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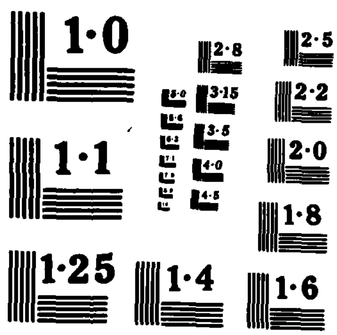
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ELECTRICAL GROUNDING OF POWER & COMMUNICATIONS FACILITIES FOR TACTICAL OPERATIONS IN ARCTIC REGIONS

U.S. ARMY ENGINEER DISTRICT, ALASKA

CORPS OF ENGINEERS

ANCHORAGE, ALASKA

SECOND PRINTING OCTOBER 1975

Requests for copies of this report from public agencies and private organizations exhausted the supply of copies originally printed. Accordingly, a second printing of 50 copies was produced in October, 1975, by the Alaska District, Corps of Engineers to fulfill future requirements. The Permafrost Map of Alaska, Map I-445, U. S. Geological Survey, was included as Appendix D in the original printing. This publication was omitted from the second printing, but copies may be purchased for $1.00 through local offices of the U. S. Geological Survey or by mail from the following address:

U. S. GEOLOGICAL SURVEY
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FOREWORD AND ACKNOWLEDGMENTS

This report is based on research into the problems of electrical grounding of power and communications facilities for tactical operations throughout arctic and subarctic regions. This work was primarily intended to provide information to support United States Army Alaska (USARAL) and all U.S. Army troop operations in cold regions. This work was sponsored by CRREL and funded as a FY 71 and 72 Special Project 6129-02

While collecting data and investigating prior work done on this subject, it was discovered that actually very little written material was available except that which related to industry, commercial, and research practices. Acknowledgment and credit for permission to reproduce various charts and tables included in the appendix of this report are extended to the James G. Biddle Company, the Copperweld Steel Corporation, and the General Electric Company. Many other genuine sources have contributed indirectly and further acknowledgment of their work can be found throughout this report and in the bibliography and references.

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APPENDIX

1. Summary. The salient factors for establishing good grounds for power and communication equipment in the cold regions are defined as follows:

a. Discrete knowledge of terrain and soils having low resistivity. These are lake bottoms and streambeds that do not freeze solid and low resistivity mineral deposits.

b. How to test and evaluate soil resistivity.

c. A knowledge of how to construct ground electrodes and which to use for reasons of economy. (Driven rods vs. horizontal wires.)

d. An understanding of why the equipment ground should always be maintained to all portable devices and apparatus. During winter operations the "green wire" and conductor bonding is the only practical solution to assure safety.

2. Introduction. The problem of electric earth grounding in cold regions is primarily one of making good contact with high resistivity soils. Where frozen, high resistivity materials are encountered, optimum grounding of power and communication circuits can only be accomplished by special attention to both surface and subsurface terrain.[1] The fact is that the resistance of frozen soils can be ten to a hundred times higher than in the unfrozen state.

a. Permafrost, which is encountered throughout the arctic and portions of the subarctic, affects grounding. In the summer months, recognition of soil deposits may be generally helpful in establishing site locations before any tests for soil resistivity have been conducted. Relative local grounding conditions can only be established by test and measurement of the soil resistivity. Subsurface conditions are not usually homogenous and are exceedingly complex. Exploration techniques can be used to arrive at a fairly accurate resistivity of the average soil at various depths.

b. During tactical operations on icefields and glaciers or in deep snow when the arctic and subarctic are overlain with snow and ice, terrain evaluation, landform, and recognition of soils are difficult and impractical. Under these climatic and seasonal conditions, judgment and expedience are prime factors in resolving

1. "Terrain evaluation in arctic and subarctic regions," engineering manual used to support design of facilities throughout Alaska. Primarily concerned with the upper 4 feet or less of the arctic and about the upper 8 feet or less of the subarctic soil profile (TM-5-852-8).

grounding requirements. The reasons for grounding are basically to minimize hazards to life and equipment from electric shock and fire where potential may result from lightning discharges, static electricity, or faulty electrical power circuits. Low resistance paths from equipment to ground or common bonding conductors are the necessary ingredients for safe operations in any region.

c. Illustrations are included throughout this report to outline various established methods to test, measure, construct, and maintain grounding systems. Manufacturers of test equipment, electrode materials, connectors, cables, and tools have written and published many articles, booklets, and instructions on grounding practices for electrical systems.[2]

2. See References and Bibliography

3. Power Systems. Power systems and electrical equipment should always be effectively bonded and grounded to earth by cables and electrodes. These ground/bond circuits are necessary to limit the voltage which might otherwise occur through exposure to lightning or other voltages higher than that for which the circuits were designed (e.g., generator fault or possibly shorted windings of a distribution transformer where high voltage has shorted through to low voltage (system neutral concept further explained in section "System and Equipment Grounds").

a. Stationary engine generator sets and all electrical devices from source to utilization must be effectively grounded for safe operation.

b. Conductive materials inclosing electric conductors or equipment, or forming part of such equipment, are grounded to prevent a potential aboveground on these materials (specifically--metallic conduit, inclosures, frames, or supports).

c. Circuits are grounded to facilitate overcurrent device operation in case of insulation failure or ground (faults) operation of circuit breakers, fuses, and protective relays.

d. Article 250-2 of the National Electrical Code refers to all general grounding categories and requirements. Particular rules concerning the installation of conductors and equipment are listed this publication.

e. Cold regions tactical troop operations might normally include, but not necessarily be limited to, brigade operations utilizing small generators for utility tool power and lighting. Engineer batallions might have larger units in the range of 100 kilowatts to power construction equipment, e.g., batch plants, rock crushers, screening, and conveyers. Large circular saws and heavy duty power tools are also used for bridge construction, temporary building shed, entrenchments, underground storage, and bunkers.

d. "Grounding" for power systems usually refers to both system and equipment grounds which are further discussed and outlined in section"Systems and Equipment Grounds."

4. Communication systems. The general considerations for power system grounding safety are similarly applied to communications facilities. The systems designers for tactical communications equipment have considered "shock hazards" and safety engineers have attempted to isolate most problem areas by systematic incorporation of checks and tests for insulation, isolation, and protective devices.

a. The equipment for mobile tactical operations will generally consist of antennas, cables, radios, multiplex, FM, tropospheric, and switchboard vans or trailers, all of which require some sort of utilization power in the 120/208 volt range. An illustration of a typical installation is shown on figure 1. The concept of bonding[3] all equipment together to minimize the possibilities of potential difference, existing between apparatus, will in actual practice prove the most beneficial for personnel safety. During winter operations grounding by the conventional methods of driven electrodes becomes almost impossible without special drilling equipment and will continue to present a problem to troop operations whenever in the field. Experience has shown that if the earth does not have good grounding characteristics (winter operations), a counterpoise[4] (horizontal wire) can be used effectively to bond together the antenna and other "system" grounds.

3. Figure 10, section 9, illustrates the "bonding" principle in relationship to "grounding."
4. See section 13, "Electrodes" for a complete description of "counterpoise."

b. The high-HF, VHF and on-upwards range of radio equipment does not seem to be seriously hampered by poor grounds. It seems some signal/noise quality improvement might under certain conditions be attained by improved grounding, but, to date, tests and the relative merits of low resistance grounding have not been established for the equipment presently being used. Low resistance grounding for lightning protection of tactical communications facilities during the summer months would prove to be too expensive and the use of "protectors" and carbon block is prescribed for use in these instances.[5]

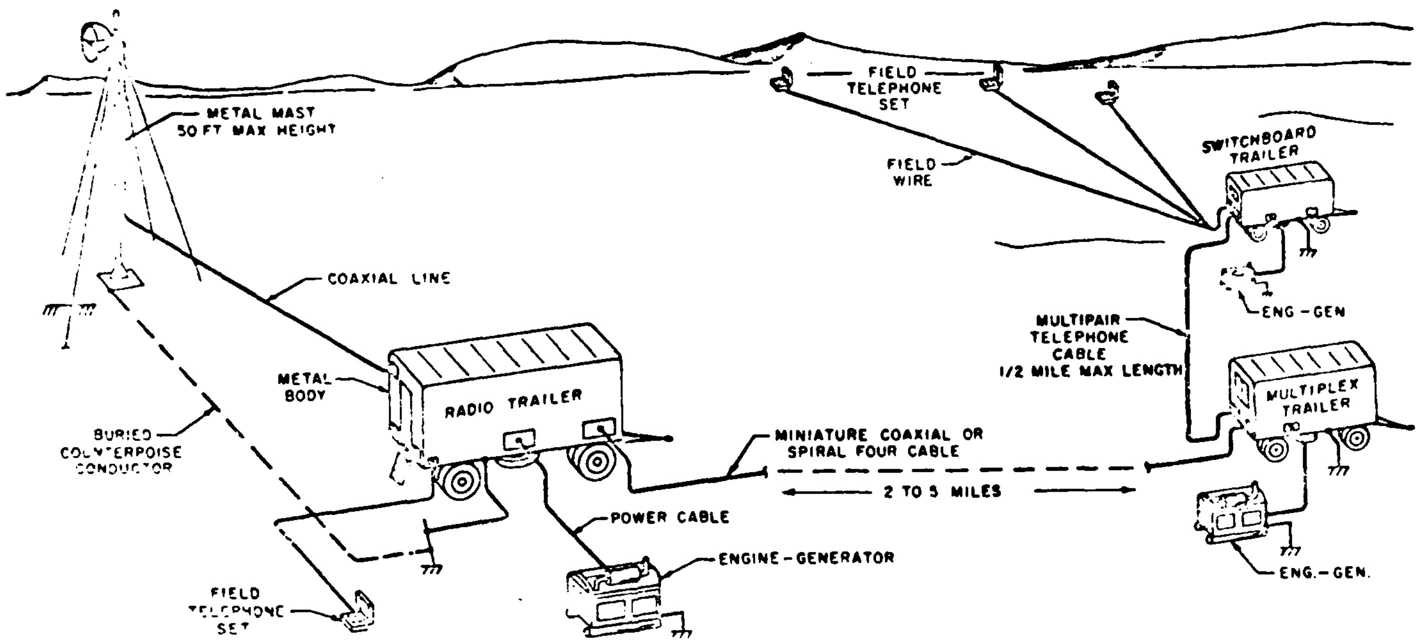
c. Fixed station communications grounding requires relatively low resistance values and criteria for the construction operation and maintenance of these grounds are part of the Defense Communications Agencies published circulars.[6] Further antenna tower grounding criteria and procedures,[7] and specific electromagnetic compatability factors all requiring bonding and grounding principles are more important for fixed facilities.[8]

d. The correct use of power distribution conductors for tactical communications systems has been a problem.

5. Electrical protection of tactical communications systems, AD 693 300.
6. DCA Cir 322.5
   DCA Cir 300-175-1
7. Electronic Institute of America, std RS-222-A PDR 13, Antennas
8. Electronic Institute America
   Bulletin No. 5 - (Bonding)
   Bulletin No. 6 - (Grounding)

Color Coding (black, white, red, blue, and green wire sequence) and correct polarization and interchangeability of connectors and plugs will in all cases improve tactical signal operations. Section 12, Figure 14, illustrates basic power configurations using single-phase 3-wire services. For three-phase 4-wire services, the additional phase or power wire will be identified by a blue tag or other special means.

e. Telephone equipment for tactical operations is not generally grounded for integrity or signaling purposes, but rather uses tip and ring or twisted pair connections to perform this function. Conversely, central station or fixed plant grounding requires low resistance or impedance paths.



OVER-ALL VIEW OF RADIO RELAY-MULTIPLEX FACILITIES

FIGURE (1)

5. Resistivity of soils. The basic concept of grounding or earthing relates to the resistivity of soils. When a certain resistance value is required, the type and quantity of electrodes can be predicted if the soil resistivity is known. The following concepts relate to soil resistivity and measuring techniques.

a. Resistivity is expressed in ohm-centimeters and by definition is the "Specific Resistance" of a 1-centimeter cube of soil between parallel planes. Dimensionally, its value is ohms per cubic centimeter, but usually is contracted to ohm-centimeter or a lesser unit value of ohm-meter (predominantly used while working in ultra high resistivity materials such as ice, snow, and rock).

b. Resistivity is dependent on type of soil, moisture content, temperature, and dissolved minerals. Seasonal changes in temperatures and moisture also affect the soil resistance and consequently all "specific resistance" values are obtained by measurement. See tables 1 through 5,page13, for characteristics of soil resistivity.

c. The "Wenner Configuration" was developed by Dr. Frank Wenner of the U.S. Bureau of Standards to test and measure resistivity of earth and is also known as the "four terminal method." The equipment normally consists of four small rods placed in line with

points driven into the ground, connected to a current source as shown in figure 2, page 14.

The following formula applies:

$$p = 6.28\ AR$$

in which

p is the average soil resistivity to depth "A" in Ohm-CM,

A is the distance between the rods in centimeters.

R is measured resistance in ohms.

Since "A" is usually measured in feet rather than in centimeters, for convenience, the formula can be converted into the following form:

$$p = 191.5\ AR$$

d. Soil resistivity measurement by the "Four Terminal Method" requires electrodes placed in the ground in a straight line at uniform spacing and an instrument that provides a current flow between the two outer pins with the potential or voltage being sensed between the inner two pins. Balance of the instrument indicates directly the ratio of the two quantities in units of resistance, ohms, and is the R factor in the foregoing equation.

e. Readings taken at pin spacing "A" are commonly referred to as the resistivity to depth "A" where actually it is the average resistivity since a different electrode spacing might give another

value of resistance. Considering that the top surface layers of earth are usually organic or topsoil; then proceeding deeper into where sand, gravel, or a loamy mixture might exist, resistance values are effected accordingly. Readings can be taken at various increases in spacing "A" and when the resistivity values change, so have the subsurface material layers. Core samples can be taken to substantiate the different materials encountered. Figure 2 and the corresponding tabulation on page 14 illustrates a theoretical cross section of soil layers.

f. Recently CRREL research has investigated resistivity measurements using low frequency electromagnetic sensors. In this application airborne equipment traverses the area to be mapped and plots radio waves. Transmitters and receivers are used and the instrumentation acts like an electromagnetometer. Resistivity mapping is thus accomplished.

TABLE 1 —Resistivities of Different Soils*

SOIL	RESISTIVITY OHM-CM AVERAGE	MIN.	MAX.
Fills—ashes, cinders, brine wastes	2,370	590	7,000
Clay, shale, gumbo, loam	4,060	340	16,300
Same—with varying proportions of sand and gravel	15,800	1,020	135,000
Gravel, sand, stones, with little clay or loam	94,000	59,000	458,000

* U. S. Bureau of Standards Technical Report 108

TABLE 2 —Resistivities of Different Soils**

SOIL	RESISTIVITY, OHM-CM (RANGE)
Surface soils, loam, etc.	100 — 5,000
Clay	200 — 10,000
Sand and gravel	5,000 — 100,000
Surface limestone	10,000 — 1,000,000
Limestones	500 — 400,000
Shales	500 — 10,000
Sandstone	2,000 — 200,000
Granites, basalts, etc.	100,000
Decomposed gneisses	5,000 — 50,000
Slates, etc.	1,000 — 10,000

** Evershed & Vignoles Bulletin 245.

TABLE 3 —Effect of Moisture Content on Earth Resistivity ‡

MOISTURE CONTENT, % BY WEIGHT	RESISTIVITY, OHM-CM TOP SOIL	SANDY LOAM
0	$1{,}000 \times 10^6$	$1{,}000 \times 10^6$
2.5	250,000	150,000
5	165,000	43,000
10	53,000	18,500
15	17,000	10,500
20	12,000	6,300
30	6,400	4,200

‡ From "An Investigation of Earthing Resistance", by P. J. Higgs, I.E.E. Jour., vol. 68, p. 736, February 1930

TABLE 4 —Effect of Salt Content on Earth Resistivity**

ADDED SALT % BY WEIGHT OF MOISTURE	RESISTIVITY, OHM-CM
0	10,700
0.1	1,800
1.0	460
5	190
10	130
20	100

** For sandy loam—moisture content, 15% by weight; temperature, 17°C (63°F).

TABLE 5 —Effect of Temperature on Earth Resistivity†

TEMPERATURE C	F	RESISTIVITY, OHM CM
20	68	7,200
10	50	9,900
0	32 (water)	13,800
0	32 (ice)	30,000
5	23	79,000
15	14	330,000

† For sandy loam, 15.2% moisture.

* By "salt" we mean not just the kind you use to season food (sodium chloride) though this kind can occur in the soil. Other kinds include copper sulphate, sodium carbonate, and others (see "Treatment of Soil", Section I, P. 27).

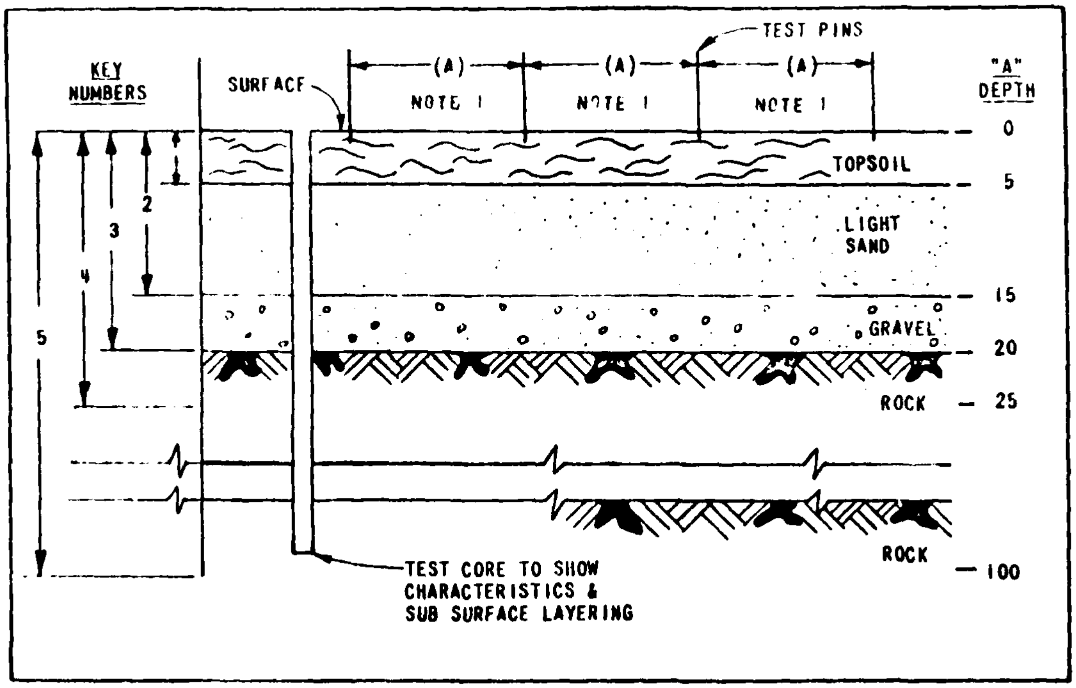


FIGURE (2)

THIS FIGURE ILLUSTRATES THE HORIZONTAL LAYER CONCEPT -

TABLE - SHOWING TYPICAL VALUES AND THEORETICAL CHANGES IN DEPTH VS RESISTIVITY.

KEY NUMBERS	AVERAGE RESISTIVITY OHM-CM	CONSTANT	DISTANCE CM. FT.	CONV.	RESISTANCE OHMS NOTE 4
1 NOTE 2	10,000 / 50,000 (B)	2π	5	12X2.54	5.22
2	40,000	↓	15	↓	13.95
3	80,000	↓	20	↓	20.90
4	750,000	↓	25	↓	157.00
5	1,300,000	↓	100	↓	67.80

NOTES:

1. PIN SPACING VARIES - COINSIDES WITH DEPTHS SHOWN BY KEY NUMBERS 1, 2, 3, 4, 5, IN FIGURE (2) & TABULATION.
2. TOP LAYER OR SURFACE LAYER MAY BE HIGH IN RELATION TO NEXT STRATA DOWN.
3. FOR NEARLY HOMOGENEOUS OR LIKE SOILS THERE WOULD BE VERY SMALL CHANGES IN "R" WITH DEPTH.
4. MEASURED OR INDICATED RESISTANCE DESCRIBED PAR B PG 25. FIG 7 OF THIS REPORT

6. <u>Terrain Evaluation</u> in the cold regions can prove to be another helpful tool and guide for securing good grounds. Especially in tactical situations a brief and basic knowledge of the surface terrain and usual underlying soil structure is desirable.

a. Permafrost occurs in various degrees throughout much of the arctic and subarctic regions. Generally in Alaska there is no permafrost along the southernmost boundary from the Aleutian Islands on the west along the southern coast of Alaska down through the southeastern panhandle. A "permafrost map of Alaska" outlines the permafrost zones of Alaska (appendix D).

b. The depth and extent of permafrost is illustrated generally by figure 3. "Permafrost is defined here as that part of the lithosphere *(upper crust of the earth)* in which a naturally occurring temperature below 0° C. (32° F.) has existed continuously for two or more years."[9] All materials whether silt, sand, gravel, or rock, independent of moisture content, if frozen as just previously defined, are included in the category of "permafrost."[10]

c. The "annual frost zone" is the zone of annual freezing and thawing. Where permafrost occurs the thickness of this surface layer varies from less than one foot in the arctic to depths in excess of 12 feet in the subarctic. The seasonal thaw zone remains

9. Ferrian's explanation on Map-1-445.
10. The characteristics of permafrost are many and further explanation can be found in the references by Muller.

unfrozen only during the short summer months. During this period, it is possible to recognize terrain features. Terrain features can also be located in the spring and fall if there's little or no snow cover. In northern arctic areas having a very shallow surface thaw layers, horizontal rods or wires might be easier to install than driven rods. Further evaluation of the two types of configurations can be found in Section 13, "Electrodes."

d. Willow groves or aspen generally point to the absence of permafrost and to the presence of groundwater which freezes only for a short time.[11] River bottoms and lake bottoms are usually frost free. Generally, slow moving rivers and streams freeze from the top down (surface ice). Clear fast moving rivers and streams usually freeze from the bottom up (anchor ice).

e. Mountains, valleys, lake bottoms, streambeds, tree-covered slopes, tundra plains, swamplands, ice glaciers, silty estuaries, permafrost areas, and seasonally frozen ground, each will be found to affect soil resistivity. Consequently, it is easily seen how one area versus another might be more suitable for good grounding. Basic illustrations of variations, layering, and asymmetrical contouring can be found in figures 3, 4, and 5.

11. Muller; - Permafrost and Vegetation, p. 32.33.

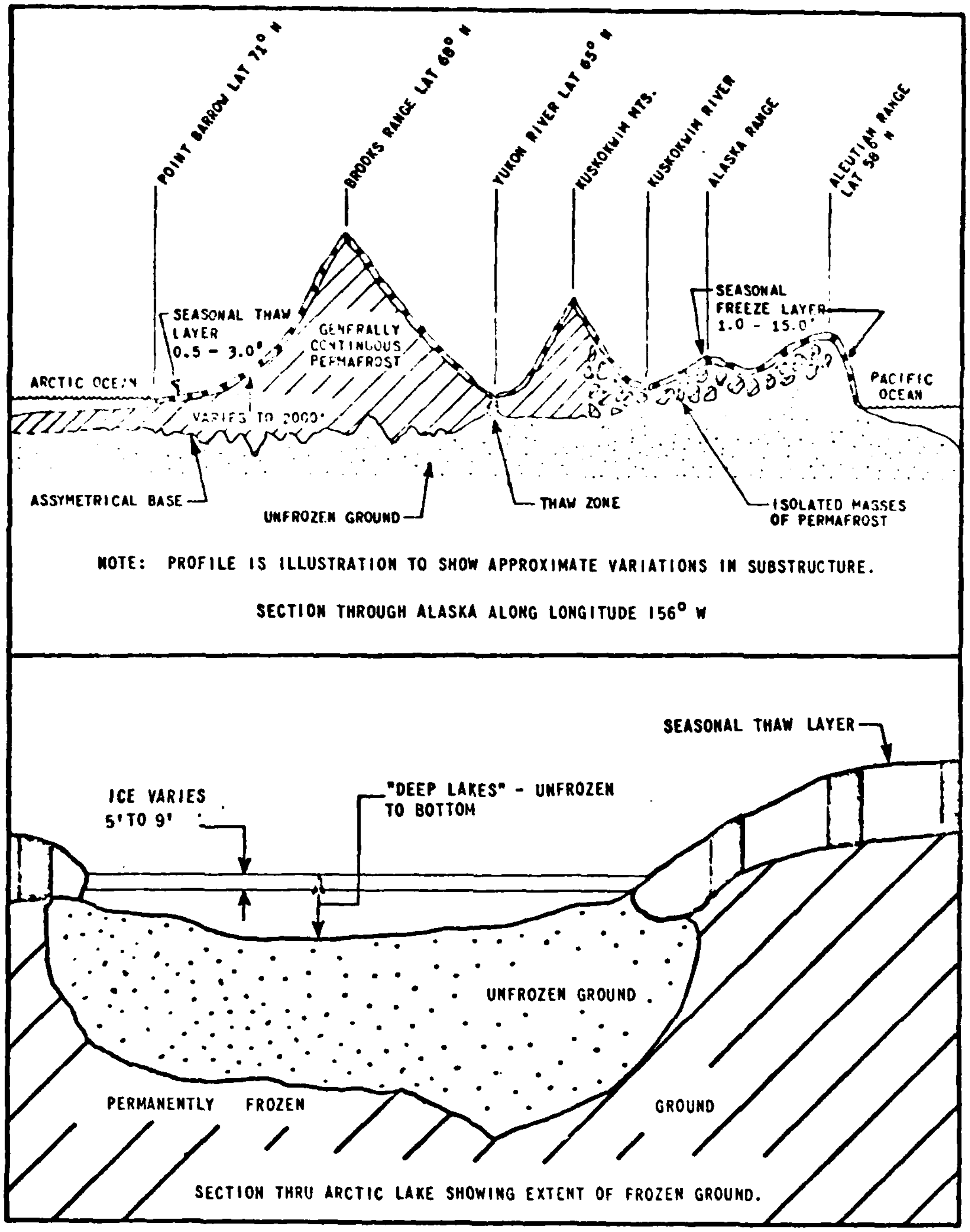

POINT BARROW LAT 71° N
BROOKS RANGE LAT 68° N
YUKON RIVER LAT 65° N
KUSKOKWIM MTS.
KUSKOKWIM RIVER
ALASKA RANGE
ALEUTIAN RANGE LAT 58° N
SEASONAL THAW LAYER 0.5 - 3.0'
GENERALLY CONTINUOUS PERMAFROST
SEASONAL FREEZE LAYER 1.0 - 15.0'
ARCTIC OCEAN
PACIFIC OCEAN
VARIES TO 2000'
ASSYMETRICAL BASE
UNFROZEN GROUND
THAW ZONE
ISOLATED MASSES OF PERMAFROST
NOTE: PROFILE IS ILLUSTRATION TO SHOW APPROXIMATE VARIATIONS IN SUBSTRUCTURE.
SECTION THROUGH ALASKA ALONG LONGITUDE 156° W
SEASONAL THAW LAYER
ICE VARIES 5' TO 9'
"DEEP LAKES" - UNFROZEN TO BOTTOM
UNFROZEN GROUND
PERMANENTLY FROZEN
GROUND
SECTION THRU ARCTIC LAKE SHOWING EXTENT OF FROZEN GROUND.

FIGURE (3)

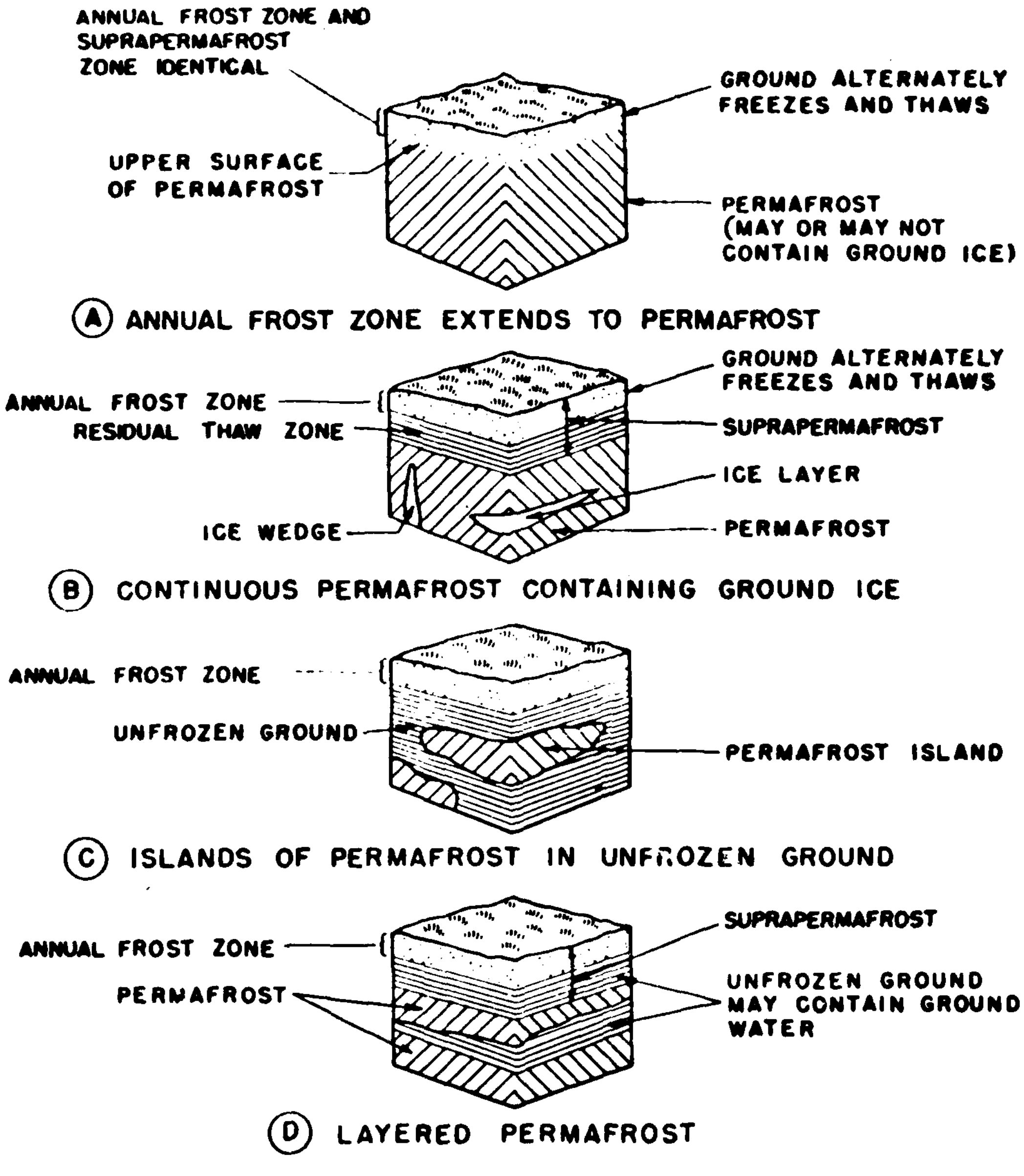
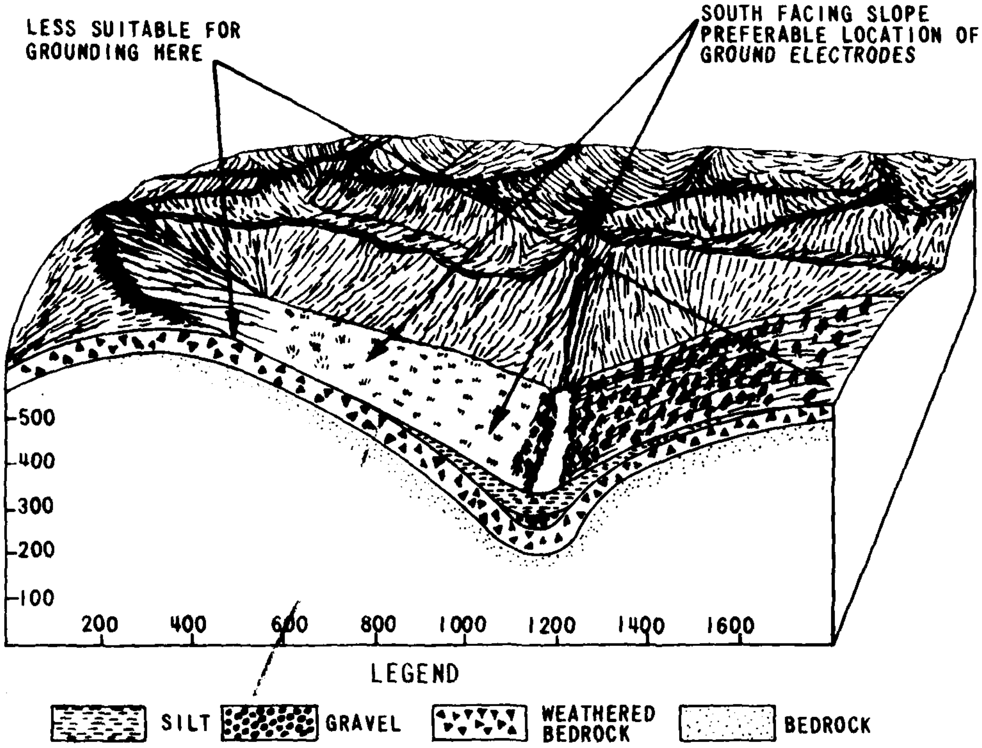


Figure 13. Typical sections through ground containing permafrost

FIGURE (4)



METAMORPHIC ROCKS AND ASSOCIATED SOILS. A SECTION ILLUSTRATING THE RELATIVE DEPTHS OF UNCONSOLIDATED MATERIALS MANTLING SCHIST BEDROCK HILLS IN SUBARCTIC ALASKA. RESIDUAL SOILS ON RIDGES AND UPPER SLOPES ARE VERY THIN. ON LOWER SLOPES, FINE-GRAINED ALLUVIAL AND COLLUVIAL SOILS ACCUMULATED BY WATER AND GRAVITY ACTION VARY IN THICKNESS FROM A VERY FEW FEET TO AS MUCH AS 10 FT. THE FILLED-IN VALLEY USUALLY CONTAINS A 10- TO 20-FT. STRATUM OF GRAVELLY MATERIALS OVER FRACTURED BEDROCK AND A SILT AND PEAT OVERBURDEN RANGING IN THICKNESS FROM 10 TO 200 FT. IN THE VALLY FILL AT THIS LOCATION, PERMAFROST USUALLY EXTENDS THROUGH THE SILT OVERBURDEN AND FREQUENTLY INTO THE GRAVEL AND FRACTURED BEDROCK STRATA. IN INTERIOR ALASKA NORTH-FACING SLOPES (ON THE RIGHT IN THIS PHOTO) SUPPORT SPRUCE-BIRCH FORESTS AND USUALLY CONTAIN PERMAFROST WITHIN 3 TO 5 FT. OF THE SURFACE, WHILE THE ASPEN-COVERED SOUTH-FACING SLOPES ARE UNFROZEN AT THE MID-SLOPE POINT.

FIGURE (5)

7. Resistance to ground and configuration of electrodes are further parameters that must be considered. The conductivity of cables and overhead wire systems are relatively high in comparison to the earth. Without the presence of minerals, dissolved salts, and moisture, clean dry soil can be classified as an insulator and posses the intermediate characteristics of a semiconductor.

a. Seasonal freezing accounts for a reduced conductivity as illustrated by table 5, page 13. If frozen soil or earth has a low conductivity, then providing larger effective electrodes will reduce the ground resistance. Whether to install multiple electrodes or single deep, driven rods, or horizontal wires, the decision will usually be dependent on soils types and the economies of placement. Earth "electrodes" are discussed and presented in a separate subsequent action.

b. "Calculation of Resistance to Ground" by H.B. Dwight and formulas for 14 different configurations are shown in table 6[12]. These formulas would not normally concern troop or tactical mission operations and are shown here, only to illustrate the difference.

12. Five of the formulas shown on table 6 are plotted on figure 6. A computer program was written for the complete series of configurations where the resistance is shown as directly proportional to the resistivity and a log function of the shape and physical dimensions.

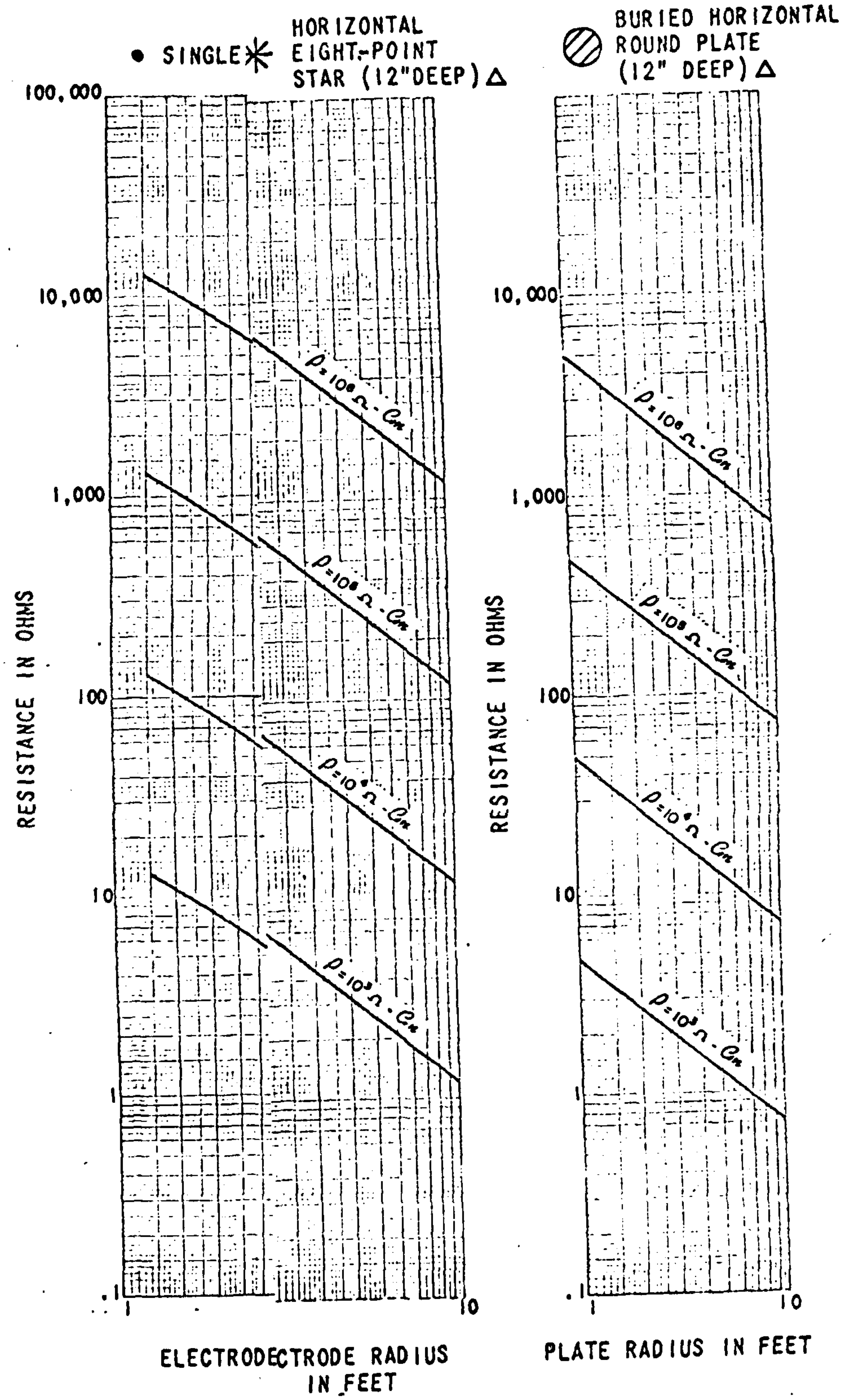
TABLE 6 –Formulas for the Calculation of Resistances to Ground ✳

(Approximate formulas including effects of images. Dimensions must be in centimeters to give resistance in ohms.)

	Hemisphere Radius a	$R = \frac{\rho}{2\pi a}$
	One Ground Rod Length L, radius a	$R = \frac{\rho}{2\pi L}\left(\log_e \frac{4L}{a} - 1\right)$
	Two Ground Rods $s > L$; spacing s	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{4L}{a} - 1\right) + \frac{\rho}{4\pi s}\left(1 - \frac{L^2}{3s^2} + \frac{2}{5}\frac{L^4}{s^4}\cdots\right)$
	Two Ground Rods $s < L$; spacing s	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{4L}{a} + \log_e \frac{4L}{s} - 2 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^4}\cdots\right)$
	Buried Horizontal Wire Length $2L$, depth $s/2$	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{4L}{a} + \log_e \frac{4L}{s} - 2 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^4}\cdots\right)$
	Right-Angle Turn of Wire Length of arm L, depth $s/2$	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} - 0.2373 + 0.2146\frac{s}{L} + 0.1035\frac{s^2}{L^2} - 0.0424\frac{s^4}{L^4}\cdots\right)$
	Three-Point Star Length of arm L, depth $s/2$	$R = \frac{\rho}{6\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} + 1.071 - 0.209\frac{s}{L} + 0.238\frac{s^2}{L^2} - 0.054\frac{s^4}{L^4}\right)$
	Four-Point Star Length of arm L, depth $s/2$	$R = \frac{\rho}{8\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} + 2.912 - 1.071\frac{s}{L} + 0.645\frac{s^2}{L^2} - 0.145\frac{s^4}{L^4}\cdots\right)$
	Six-Point Star Length of arm L, depth $s/2$	$R = \frac{\rho}{12\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} + 6.851 - 3.128\frac{s}{L} + 1.758\frac{s^2}{L^2} - 0.490\frac{s^4}{L^4}\right)$
	Eight-Point Star Length of arm L, depth $s/2$	$R = \frac{\rho}{16\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} + 10.98 - 5.51\frac{s}{L} + 3.26\frac{s^2}{L^2} - 1.17\frac{s^4}{L^4}\cdots\right)$
	Ring of Wire Diameter of ring D, diameter of wire d, depth $s/2$	$R = \frac{\rho}{2\pi^2 D}\left(\log_e \frac{8D}{d} + \log_e \frac{4D}{s}\right)$
	Buried Horizontal Strip Length $2L$, section a by b, depth $s/2$, $b < a/8$	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{4L}{a} + \frac{a^2 - \pi ab}{2(a+b)^2} + \log_e \frac{4L}{s} - 1 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^4}\cdots\right)$
	Buried Horizontal Round Plate Radius a, depth $s/2$	$R = \frac{\rho}{8a} + \frac{\rho}{4\pi s}\left(1 - \frac{7}{12}\frac{a^2}{s^2} + \frac{33}{40}\frac{a^4}{s^4}\cdots\right)$
	Buried Vertical Round Plate Radius a, depth $s/2$	$R = \frac{\rho}{8a} + \frac{\rho}{4\pi s}\left(1 + \frac{7}{24}\frac{a^2}{s^2} + \frac{99}{320}\frac{a^4}{s^4}\cdots\right)$

"Calculation of Resistance to Ground," by H. B. Dwight, Electrical Engineering, vol. 55, p. 1319, December, 1936.

✳ **REPRINTED FROM GENERAL ELECTRIC CO, INDUSTRIAL POWER SYSTEMS DATA BOOK.**


• SINGLE
HORIZONTAL EIGHT-POINT STAR (12"DEEP) △
BURIED HORIZONTAL ROUND PLATE (12" DEEP) △
100,000
10,000
1,000
100
10
1
.1
RESISTANCE IN OHMS
ρ=10⁶ Ω-Cm
ρ=10⁵ Ω-Cm
ρ=10⁴ Ω-Cm
ρ=10³ Ω-Cm
1
10
ELECTRODECTRODE RADIUS IN FEET
PLATE RADIUS IN FEET

8. Instruments and methods of test for both soil resistivity and earth resistance are basically the same. The general considerations for taking measurements of all grounding systems whether comprised of a simple single electrode or complex multiple network can be shown.

a. If a resistance of 25 ohms[13] is all that is required and and other known grounds exist, then measurement can be simplified. Accuracy will be improved if more than one measurement or a series of investigative "test readings" are made. If preliminary resistivity measurements are taken during the thaw season, then a resistivity survey to check the installed ground should be made during comparable climatic conditions. Again, as mentioned in other sections of this report, hot, cold, wet, or dry conditions will cause variations in the resistivity of the soil. If resistivity measurements were taken during a wet, relatively warm period, then a "theoretical ground" might only exist for this condition. We could not expect the ground to have a comparable resistance to ground when the soil is frozen or if the water table is lowered.

13. The value of 25 ohms is established from the safety rules for the installation and maintenance of electric supply and communication lines (National Bureau of Stds., H-31)

Arctic, and to a lesser degree, subarctic regions are those which experience the greatest differential temperature range. Resistivities of soils vary over wide ranges, consequently, measurements taken vary greatly from high or poor to low or good. Recommendations for suitable instruments and their characteristics are included hereafter.

b. As shown in the following figure 7, resistivity of the earth may be determined from resistance measurements made with a null-balance tester. Four ground rods connected to terminals C1, C2, P1, and P2 are placed in a straight line any distance "A" apart and driven into the ground to a depth of not more than A/20. With the tester resistance adjusted to give zero deflection of the needle, the indicated resistance may be substituted into the formula given on page 11.

$$p = 191.5AR, \text{ A. being in feet.}$$

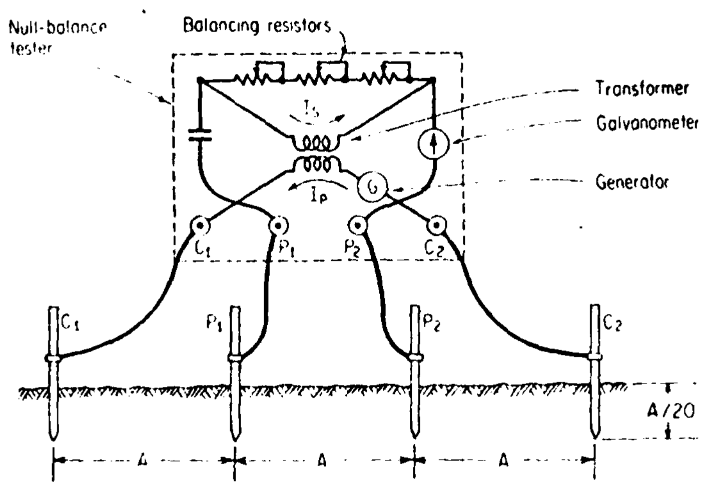


FIGURE (7)
SHOWING MEASUREMENT OF RESISTIVITY

14. Appendix C illustrates test instruments.

c. If a fixed station ground is required where there are existing buried utilities then the two-terminal method, as shown in figure 8 may be used in conjunction with a water-pipe provided that:

(1) The water pipe system is metallic throughout with no insulating couplings or flanges;

(3) The earth electrode under test is far enough from the water pipe system to be outside its sphere or influence.

If a driven ground rod were substituted for the water pipe system, the tester would indicate the resistance of the two electrodes in series, but the individual resistance of each would be unknown. This test could be useful where it is only necessary to know that a given electrode's resistance to earth falls below a stipulated value, say 25 ohms. If the results of the test show the combined earth resistance to be 25 ohms or less, it is obvious that each of the two must be less than 25 ohms. Since the water pipe system's resistance to earth was considered to be negligible, the resistance indicated by the meter will be that of the earth electrode.

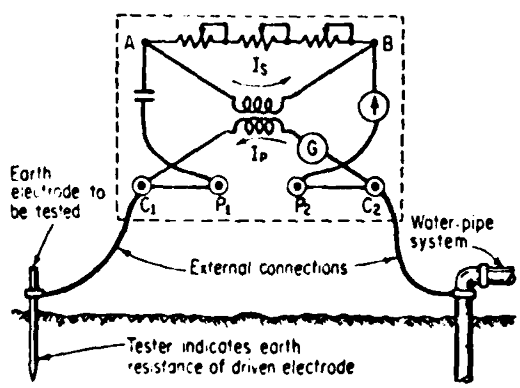


FIGURE (8)
SHOWING TWO TERMINAL (DIRECT) METHOD

d. Where no metallic water pipe system is available, the three terminal (or fall-of-potential) method shown in figure 9 may be used to determine the resistance of an earth electrode or electrode system. A ground rod C2 is driven into the earth at a considerable distance from C1 (see figure 9), both being connected to the null-balance tester. Cranking the hand generator thus sends current through the earth between the two electrodes, as in the two-terminal method. Rod P2, connected to the test galvanometer and driven at various points in turn along a straight line between C1 and C2, is subjected to varying earth potentials. Adjusting the balancing resistance at each of these points gives corresponding resistance readings which may be plotted as illustrated in figure 9. If the test readings are plotted against the distance from C1, the resulting curve will show that the ground resistance between C1 and P2 increases to a certain point, levels off, and then increases again as C2 is approached. The true resistance to earth at electrode C1 is the value at the leveled-off portion of the curve, before it is influenced by rod C2. This point will normally be reached about 62 percent of the way from rod C1 to rod C2.

e. Another method of testing a ground resistance is shown in figure 9.1. Additional rods A and B are placed remote to the unknown rod X. The formula shown will give the X value of resistance. An ohmmeter is used to record the resistances. Polarity

must be switched or leads interchanged and the average value of resistance used in the formula.

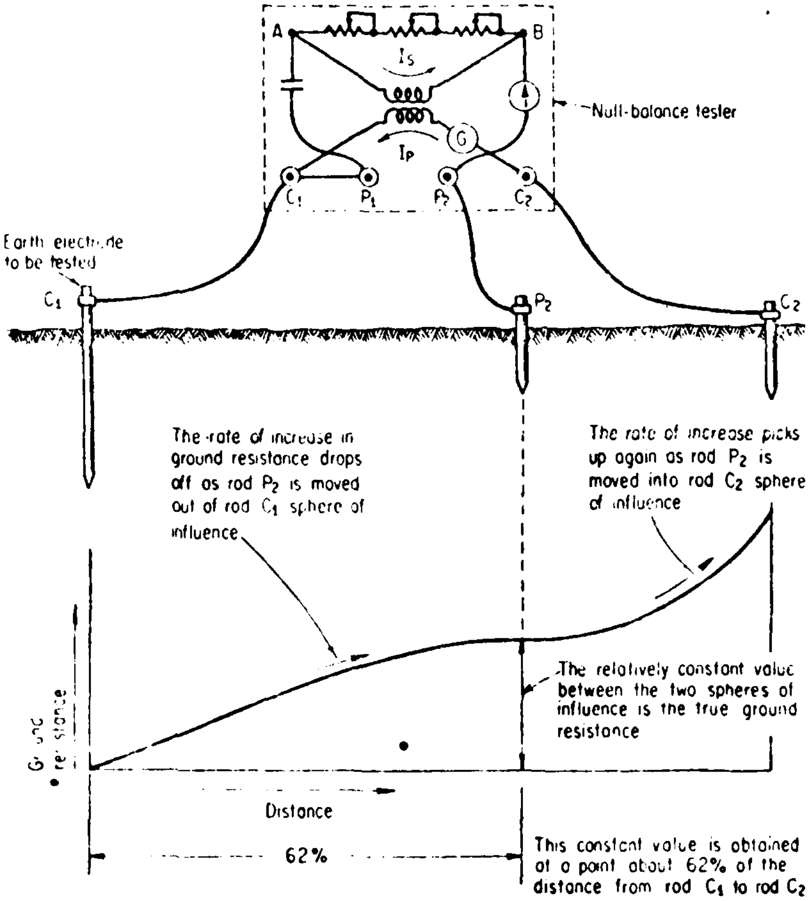


FIGURE (9)
SHOWING THREE TERMINAL (FALL OF POTENTIAL) METHOD

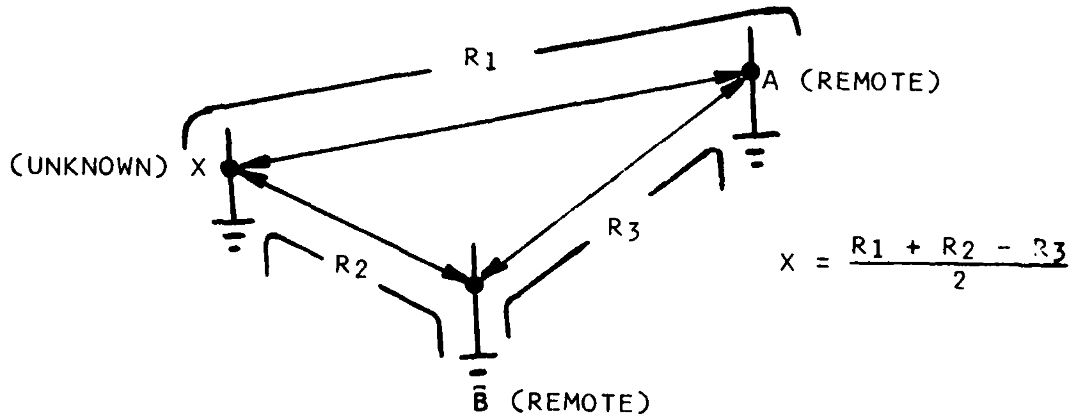


FIGURE 9.1
SHOWING DUAL REMOTE REFERENCE ELECTRODE

9. Mobile equipment, POL systems, aircraft and automotive fuel facilities all require measures for the grounding of certain equipment and piping. General electrical considerations for "Storage Distribution and Dispensing of Aircraft and Automotive Fuels"[15] are covered below:

a. Mobile equipment:[16] Cargo tanks and vehicle chassis should be electrically bonded for static protection. Provisions should be made in the tank structure of the vehicle for the bonding of vehicle to the fill pipe during truck loading operations and bond wires are recommended for aboveground handling of flammable materials.

b. POL systems in support of tactical troop operations require the same safety features established for mobile equipment. Metallic aboveground storage tanks and fuel piping systems require static grounding by the bonding together of tanks and piping with copper jumpers connected to an earth electrode (1 each 3/4 inch x 8 feet vertical rod) (NMGR).[17]

c. Aircraft and automotive fuel facilities are classified as hazardous locations and both permanent and temporary sites are used during tactical operations. Fuel dispensing to aircraft requires that the nozzle be bonded to the aircraft and the truck to the aircraft which in turn is connected to the ground electrode.

15. TM-5-848-2/AFM 88-12, Chapter 2, June 1970.
16. National Fire Protection Assoc. No. 385.
17. NMGR-denotes no maximum ground resistance requirement.

For mobile tactical situations, the use of drums or bladders for storage and dispensing may be encountered. Grounding procedures as previously mentioned should be used.

d. Ground mats or counterpoises are installed along airfield aprons to drain static electricity from planes and fueling trucks, thereby eliminating hazardous conditions during fueling operations.[17.1] A gasoline truck has an electrical capacity of 700 to 1,200 micromicrofarads and can generate 15,000 to 25,000 volts between the truck body and the earth while being driven along an airfield apron or highway. Resistance values of grounds for static electricity need not be as low, however, as the resistance offered by grounds for electric power distribution systems. If the ground resistance of 500 ohms is offered to a truck or plane generating 20,000 volts and having 1,000 micromicrofarads of capacitance, approximately 1/2,000,000 second is required to discharge the truck or plane to 7,400 volts. About 1/1,000,000 second more time is needed to discharge the voltage to zero potential or a total of 1.5/1,000,000 second. If the ground resistance were 5 ohms instead of 500 ohms, complete discharge would be accomplished in 15/1,000,000 second. Therefore, 500 ohms resistance is practically as good as 5 ohms because dissipating the charge in 15 billionths of a second is little better than 1.5 millionth of a second. Even a ground resistance of some

17.1 Paragraph 114, TM-5-680, Electrical Facilities.

1,000,000,000 ohms would permit a static change of 20,000 volts to be dissipated in 3 seconds.

e. During winter tactical situtations, because of snow covered frozen ground and the location-logistic-time factors involved, the expedient solution is to bond all metal bladder fill pipes, oil drums and dispensing vehicle and fuel recipient devices in a common loop or grid to equalize static electric potentials resulting from fuel flow in pipe lines or accumulation of static charges on moving vehicles. The bonding cable should be flexible bare copper wire, #4 AWG minimum with suitable heavy duty clamps for quick temporary connections and bolted lugs for semipermanent and permanent connections.

f. Bonding and grounding are two terms misused interchangeably and a simple clarification can be best illustrated by figure 10. Bonding theoretically reduces the potential difference between apparatus and objects. Grounding reduces the potential difference between apparatus or objects and ground. Conductivity between objects must be established by bonding using wires, bus bars, and/or metallic inclosures. Conductivity to ground should be established where ever possible. The National Electrical Safety, Fire and Underwriters Codes provide the current standards for minimum bonding and grounding. The bonding of containers is shown in figure 11.

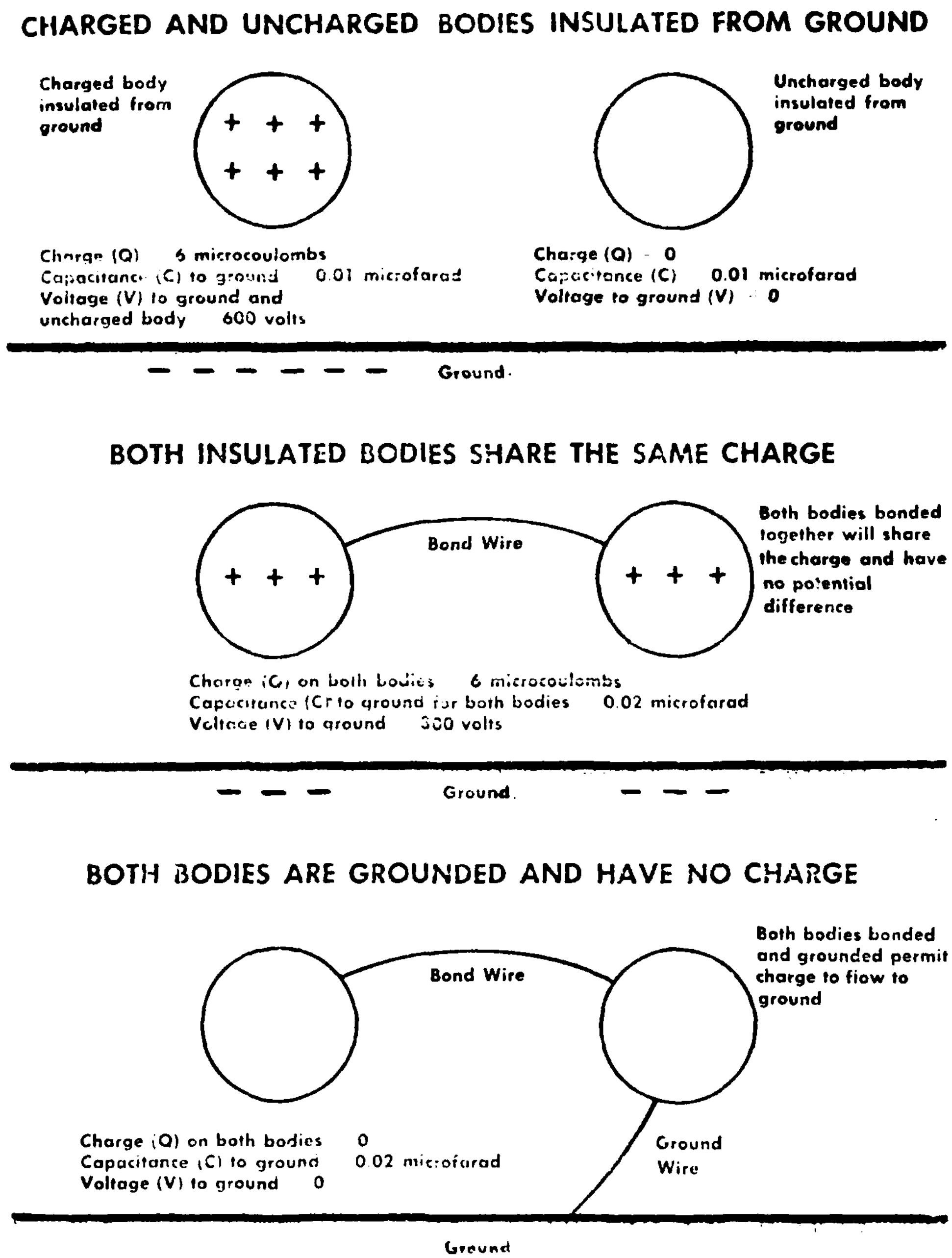
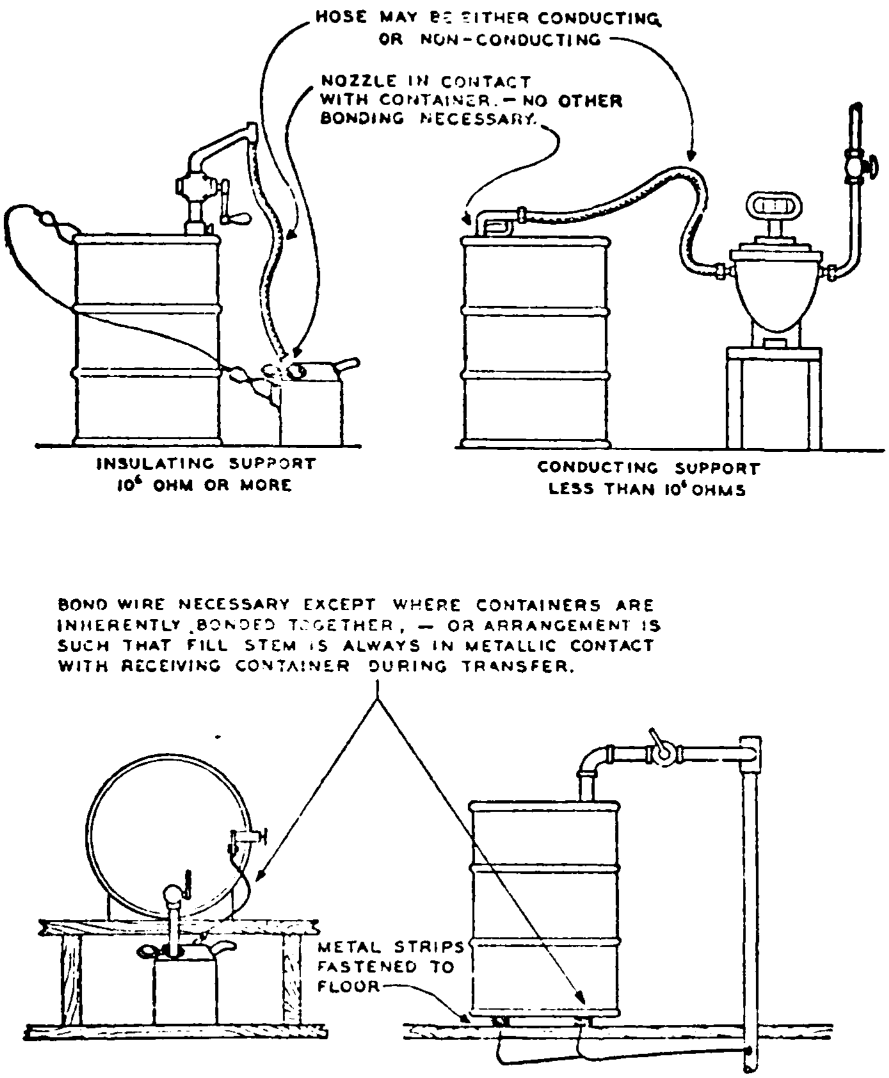


FIGURE (10)

SHOWING BONDING & GROUNDING PRINCIPALS - STATIC ELECTRICITY

COURTESY OF NATIONAL SAFETY COUNCIL



BONDING DURING CONTAINER FILLING PERMITS SAFE DISCHARGE OF ANY STATIC ELECTRICITY GENERATED.

FIGURE (11)

SHOWING THE BONDING OF CONTAINERS

COURTESY NATIONAL FIRE PROTECTION ASSOCIATION

10. <u>Lightning protection</u> of equipment and personnel in the field during tactical operations should not differ from any other type of operation. If hazardous conditions exist and potential danger is imminent, then certain precautions are warranted. The seasonal occurrence of lightning in parts of interior Alaska causes many fires. Damage to equipment and potential hazard to life and personnel are altogether possible. A few basic rules and general measures for safety during field maneuvers can be adopted where lightning hazards exist.

a. Overhead lines, antennas, high structures, and ammo storage dumps if unprotected, all are subject to potential lightning strokes. Lightning rods (air terminals), and overhead ground wires can be used to shield or provide zones of protection when exposure to lightning stroke and preventive measures become necessary. There will be little doubt concerning the need for protection when operations are concentrated within a high incidence zone of lightning occurrence.

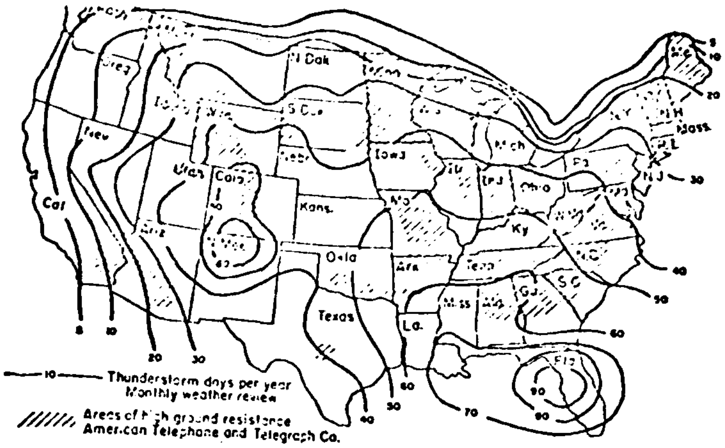
b. Annual occurrence of lightning throughout the Alaskan arctic regions can be expected to start during the month of May, building to maximums in mid-June and July, then diminishing by late August which marks the end of the seasonal incidence.

c. Figure 12 shows the annual isokeraunic maps illustrating the number of thunderstorm days per year throughout the lower 48 states and Alaska.

d. Alaskan lightning incidence during the summer months varies from very little or none to high frequency. The high maximum frequency occurs between Fairbanks and the Brooks Range located to the north, favoring the low-lying ranges of hills between the Brooks and Alaska Ranges. The highest density occurs between Fairbanks and Rampart and diminishes toward the Canadian border on the east, the coast on the west, and the Gulf of Alaska to the south.

e. Protection for overhead lines, communications equipment, towers, antennas, or high structures can be accomplished by grounding all metallic parts to earth electrodes. Usually, antenna guying systems incorporate hold down rods on each guy and tower base. The electrode method would, in low and medium resistivity soil areas, provide adequate grounding.

(1) Overhead lines, and in this case either communications or low voltage power require lightning arrestors placed at cable runs or adjacent to equipment to limit overvoltage and the followup high currents experienced during and after a direct lightning stroke on the line. Communications equipment would usually be protected for safety and dependability.



ANNUAL ISOKERAUNIC MAP SHOWING THE NUMBER OF THUNDERSTORM DAYS PER YEAR.
(COURTESY AMERICAN TELEPHONE & TELEGRAPH CO.)

FIGURE 12

Showing 1971 Alaskan Thunderstorm Insidence*

Number of Thunderstorms and Stations

≥ 15	≥ 10 but < 15	≥ 5 but < 10	< 5	
Fairbanks	Farewell	Central	Dot Lake	Sleetmute
McGrath	Sparrevohn	Fort Yukon	Eagle	McCarthy
Summit		Bettles	Big Delta	Nenana
		Indian M	Galena	Tanana
		Northway	Bethel	Tanacross
		Gulkana	Talkneeta	Kiana
		Tatalina	Minchumina	
		Nenana	Puntilla	
		Dillingham	King Salmon	

* ESSA - Local Climatological Data

11. Ammunition Storage Facilities must be protected from lightning. Low resistance grounds which are connected to either air terminals or an overhead ground wire must be periodically checked for continuity and maximum permissible resistance values.[18]

a. "Magazines" by definition include such phases as an above ground magazine, an igloo or a corbetta type magazine, a railroad car, a motor truck, a temporary shelter, or an open storage site.[19] In tactical operations the remote magazine is not usually grounded except where aircraft are being loaded with ammunition; a ground connection will be established from the aircraft to earth and in this instance the maximum resistance value should be no greater than 10,000 ohms.[20]

b. If tactical storage facilities for the care, handling, and preservation of ammunition are to be maintained for any length of time and are located in high lightning incidence areas, then recommendations and details for the construction and installation of lightning protection systems shall be adopted and in general conform with the regulations of the National Fire Protection Association.[21]

18. TM 9-1300-206, Section 16 e(1)
19. Ibid. 20 d(6)
20. Ibid. 72 e(1)
21. Lightning Protection Code NFPA No. 78, 1968

12. System and equipment grounds.

a. System grounding practices vary. This discussion of grounded paths will be demonstrated. In electrical circuits, electricity naturally flows to ground which is assumed as zero voltage level. Thus, it can be stated that all levels of voltage are aboveground The conductor path and the devices themselves must have insulating qualities of electrical strength to isolate the voltage aboveground and to prevent short circuiting of the loop or leakage of current at any single point.

b. Normally only two insulated wires are required for a single-phase circuit. The addition of a third conductor which we have grounded, or returned to the source with the circuit conductors, can be shown to improve electrical safety. This third wire is identified as the equipment ground when connected as shown in the following diagrams, figure 13.

c. The conditions of normal and faulty circuits are shown in (A) through (F) including both grounded-two-wire and grounded-three-wire conditions.

d. If grounding values are established as set forth by the National Standards and further relationships involving both practical and theoretical conditions are considered, then a further understanding of the reasons for good grounds becomes evident. The National Electrical Code, Article 250, grounding, prescribes that electrodes

41

or ground rods, if used, shall have a resistance to ground not to exceed 25 ohms. Effective grounding by code definition shall include a path, be permanent and continuous, have ample capacity to safely conduct current, and sufficiently low in resistance to limit within safe values, the potential aboveground during fault conditions.

e. Considering the foregoing, it can be shown that sometimes a 25 ohm ground may not be a safe maximum if a lower path to ground existed in proximity to any faulty circuit. Normally, the human body has a contact resistance, if dry, in the range of 200,000 ohms, and 25 ohms parallel ground path would be sufficient protection. When damp, moist, or wet conditions exist, a lower resistance contact would permit current flow through the arms, legs, or body as a person consists of approximately 98 percent fluids or water content. Electricity seeks any easy path to ground through metallic or water paths. For this reason, when possible, systems are always bonded together and connected to <u>as low a ground as possible</u>.

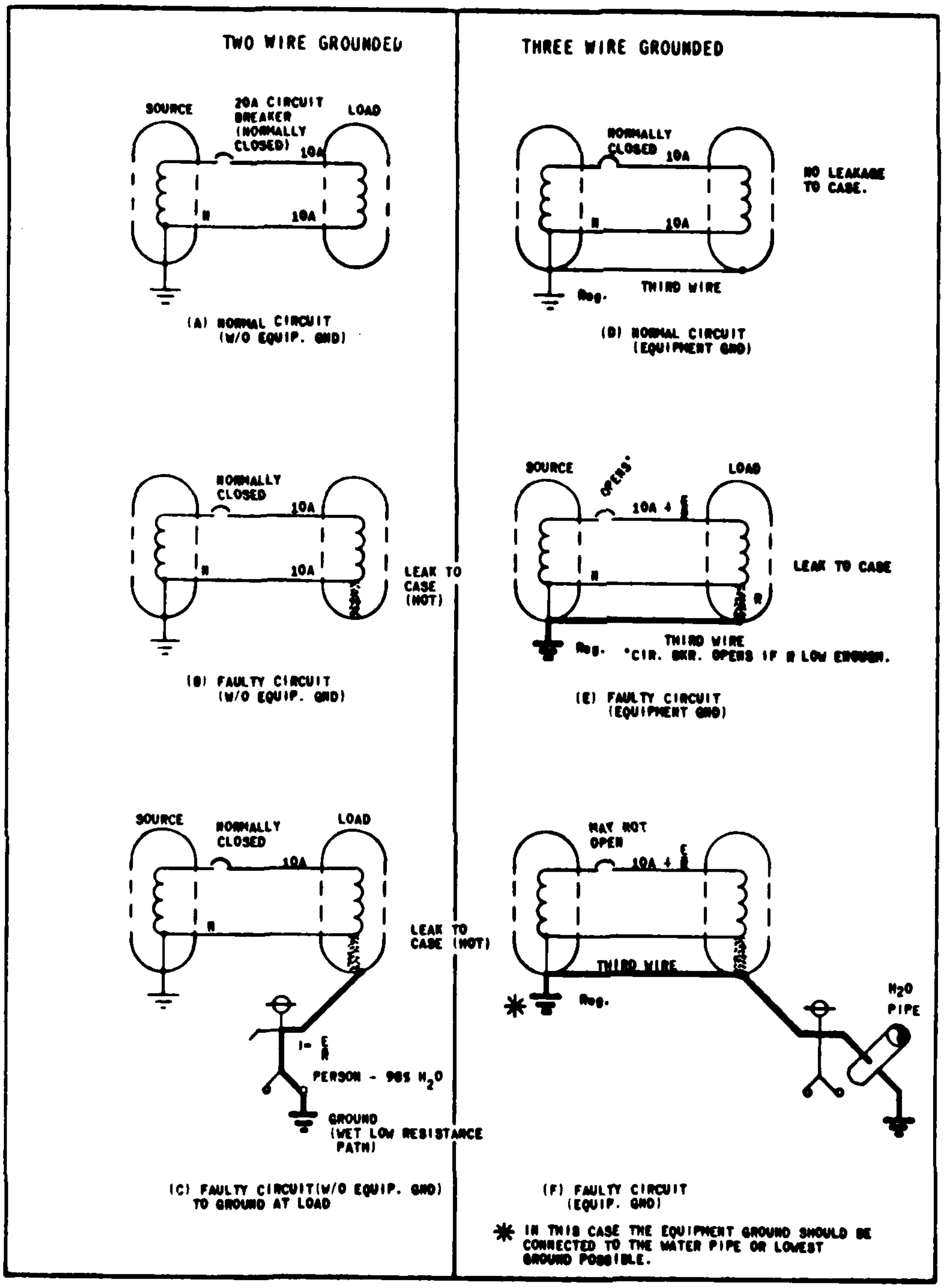
f. Color coding of conductors are required by the National Electrical Code (Article 210-5 and 250-57(b)). <u>System</u> and <u>equipment</u> ground wires are colored <u>white</u> and <u>green</u> respectively. Figure 14 shows various typical single-phase connections, color coding and their relationship.

g. In three-phase circuits, the system neutral concept reduces insulation requirements, lowers voltage to ground, and with the

proper connections and safety devices, ground fault protection can be improved. The neutral shown in figure 15 is defined as the system neutral.

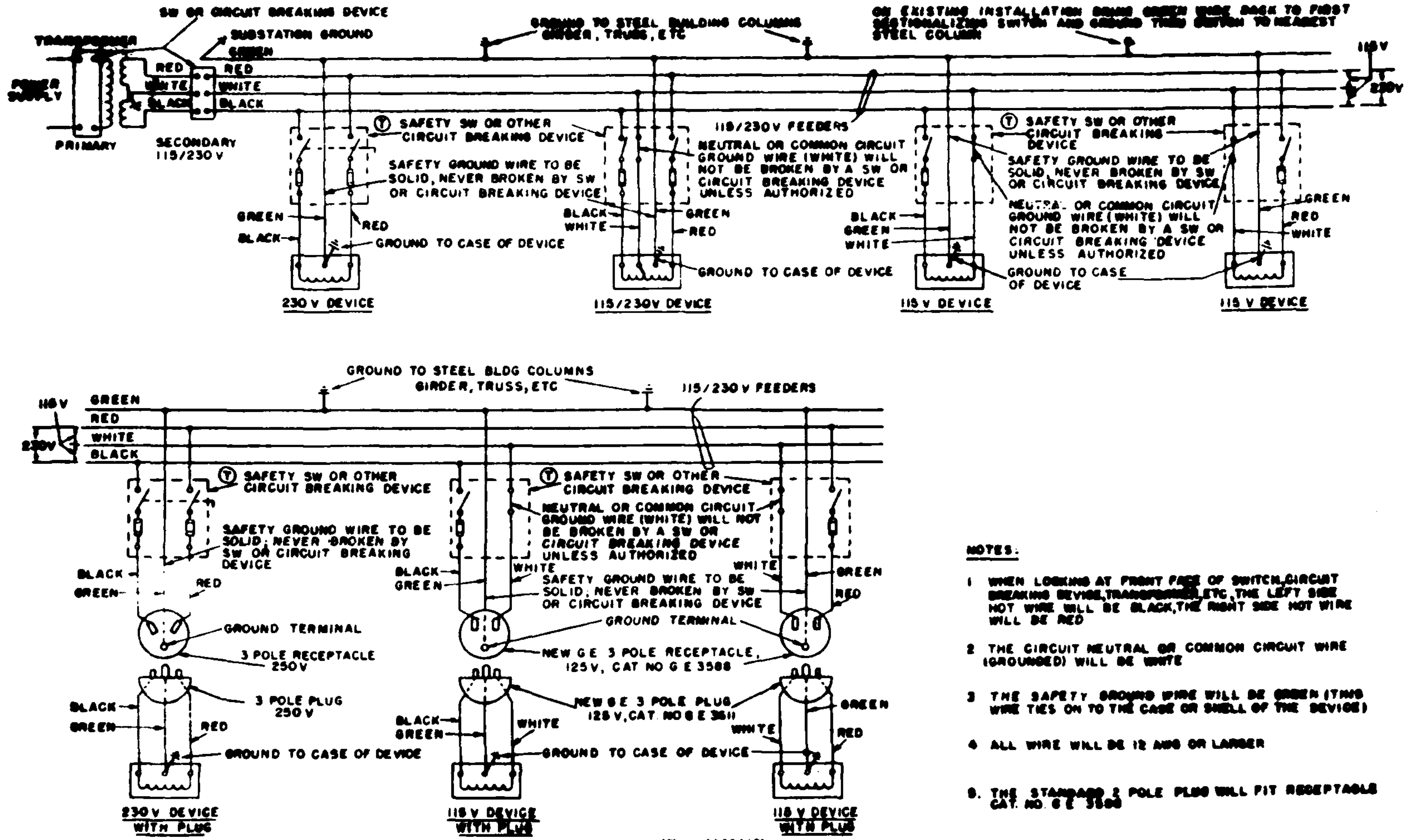
h. Ungrounded systems are those which there are no intentional ground connections between the phase conductors and ground although there always exists a capacitive coupling between the undergrounded conductors and earth. This report will not evaluate the characteristics of ungrounded systems except to say that the merits and advantages of grounded systems far outweigh the ungrounded system.[22]

22. A brief presentation of the "characteristics of ungrounded systems" can be found in the General Electric Co. Industrial Power Systems Data Book, section 30, page 2, March 5, 1956.



TWO WIRE GROUNDED
THREE WIRE GROUNDED
SOURCE
20A CIRCUIT BREAKER (NORMALLY CLOSED)
LOAD
10A
N
10A
(A) NORMAL CIRCUIT (W/O EQUIP. GND)
NORMALLY CLOSED
10A
N
10A
NO LEAKAGE TO CASE.
THIRD WIRE
Reg.
(D) NORMAL CIRCUIT (EQUIPMENT GND)
NORMALLY CLOSED
10A
N
10A
LEAK TO CASE (HOT)
(B) FAULTY CIRCUIT (W/O EQUIP. GND)
SOURCE
OPENS*
LOAD
10A + E/R
N
R
LEAK TO CASE
THIRD WIRE
Reg.
*CIR. BKR. OPENS IF R LOW ENOUGH.
(E) FAULTY CIRCUIT (EQUIPMENT GND)
SOURCE
NORMALLY CLOSED
LOAD
10A
N
LEAK TO CASE (HOT)
I= E/R
PERSON - 98% H_2O
GROUND (WET LOW RESISTANCE PATH)
(C) FAULTY CIRCUIT(W/O EQUIP. GND) TO GROUND AT LOAD
MAY NOT OPEN
10A + E/R
THIRD WIRE
Reg.
H_2O PIPE
(F) FAULTY CIRCUIT (EQUIP. GND)
* IN THIS CASE THE EQUIPMENT GROUND SHOULD BE CONNECTED TO THE WATER PIPE OR LOWEST GROUND POSSIBLE.

FIGURE (13)



NOTES:

1 WHEN LOOKING AT FRONT FACE OF SWITCH, CIRCUIT BREAKING DEVICE, TRANSFORMER, ETC, THE LEFT SIDE HOT WIRE WILL BE BLACK, THE RIGHT SIDE HOT WIRE WILL BE RED

2 THE CIRCUIT NEUTRAL OR COMMON CIRCUIT WIRE (GROUNDED) WILL BE WHITE

3 THE SAFETY GROUND WIRE WILL BE GREEN (THIS WIRE TIES ON TO THE CASE OR SHELL OF THE DEVICE)

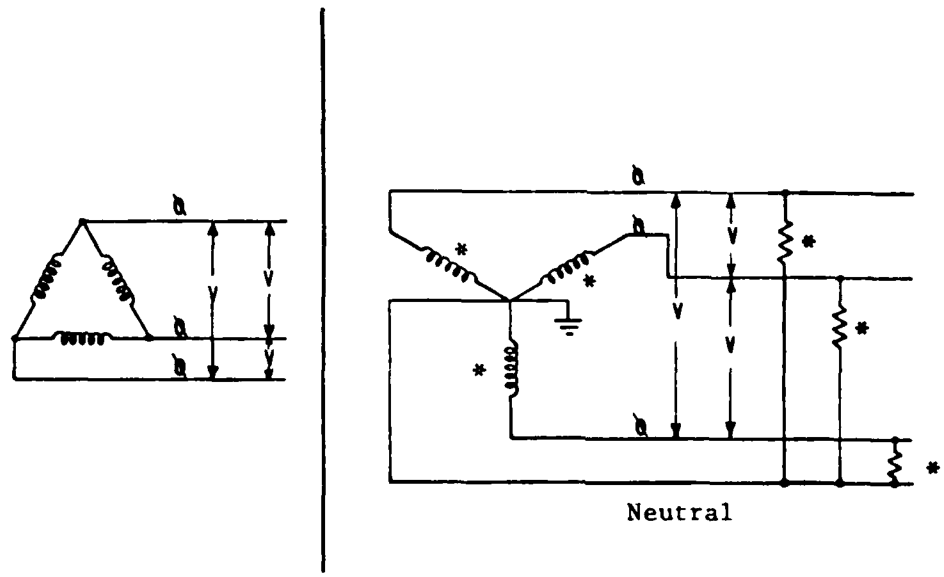
4 ALL WIRE WILL BE 12 AWG OR LARGER

5. THE STANDARD 3 POLE PLUG WILL FIT RECEPTACLE CAT. NO. G E 3588

(Photo 1100448)

Power distribution connections showing distinction between neutral conductor (white) and grounding conductor (green)

FIGURE (14)



STANDARD VOLTAGE CONFIGURATIONS

VOLTAGE RANGE	(A)	(B)
LOW	120V, 3Ø-3W	* 120/208V, 3Ø-4W
	240V	* 240/416V
	480V	* 277/480V
HIGH	2400V	* 2400/4160V
	7200V	* 7200/12,470V
	13,800V	* 14,400/24,900V

* WINDINGS ARE OF LOWER VOLTAGE RATING.

FIGURE (15)

13. Electrodes.

a. As a preface to this section, the following definitions are presented:

(1) Grounding connection: A grounding connection is a connection used in establishing a ground and consists of a grounding conductor, a grounding electrode, and earth (soil) which surrounds the electrode.

(2) Ground electrode: A grounding electrode is a conductor- embedded in the earth (soil) used for maintaining ground potential on conductors connected to it and for dissipating currents into the earth.

(3) Ground grid: A ground grid is a system of grounding electrodes with interconnected bare cables buried in the earth to provide a common ground for electrical devices and metallic structures. It may be connected to auxiliary grounding electrodes to lower its resistance.

(4) Counterpoise: A bare wire buried and run horizontally around a building, in an antenna field, along side a van, between driven rods, will be nearly as effective as driven rods.

b. Most troop operations on tactical missions which require grounding of generators, radio, telephone, and microwave equipment,

will be equipment with 3-foot arctic type rods. This rod type of electrode for driving into the earth comes either in individual or sectional lengths.

c. In the prior section on terrain evaluation, mention was made concerning placement of ground rods during the thaw time of year in permafrost regions. When thin surface layers of unfrozen materials exist, the installation of deep driven grounds would be difficult except where predrilling or augering of the hole was performed by mechanical means; therefore, in certain instances, horizontal burial of rods will prove to be more suitable. Hand excavation of a trench at shallow depths under the tundra or muskeg is not as simple as driving rods, but if "refusal" is only a few feet below the surface due to underlying permafrost, then the horizontal counterpoise position remains the next practical alternate. A grid of ground rods in a star or straight line and their resistance values were shown in section 7, table 6.

d. Electrodes by definition were shown to be conductors where surface contact and surrounding area further complete the characteristics of an earth electrode.

e. Figure 17 plots rod diameter versus percent resistance to show that diameter has little effect.

f. Figure 18 plots rod depth versus resistance in ohms to show that depth does have appreciable effect on change in resistance,

e.g., theoretically the difference between a 3-foot, 6-foot, and 9-foot rod would reduce the net resistance of the initial section by 46 percent and 62 percent respectively. This reduction under actual field conditions would not necessarily prove true in all instances as the homogenity of soil versus depth must also be considered.

g. Figures 17 and 20 graphically illustrate the approximate reduction of resistance that can be expected by use of multiple rods. Note, in these configurations the best results will occur where the spacing between rods are equal to or as great as the depth of rods. Spacing rods at distances less than their depth will result in values above theoretical minimum due to a resistive "coupling effect." A further explanation of multiple rod application follows: For example, if one rod results in 100 ohms, then theoretically, two would reduce to 50 ohms, four rods 25 ohms, eight rods 12.5 ohms, 16 rods 7.25 ohms, 32 rods 3.625 ohms, etc., but from the "figures" just presented, it can be seen that the theoretical has limitations.

h. Figure 21 illustrates that deeper single electrodes reduce the net resistance.

i. Figures 22 and 23 are plots of depth of rod versus resistance and conductance. (MHO which are reciprocal ohms.)

j. Figures 24 and 25 are representative of a method of soil treatment and a plot of time in months of the year for chemical treatment and subsequent reduction in seasonal variation of resistance in ohms.

k. Figure 26 illustrates the "sectional" type rods, their couplings, and removable drive bolts. These rods can be 3, 5, 8, or 10 feet long. The "arctic type rod" used by tactical units are usually 3 feet long each sectional length.

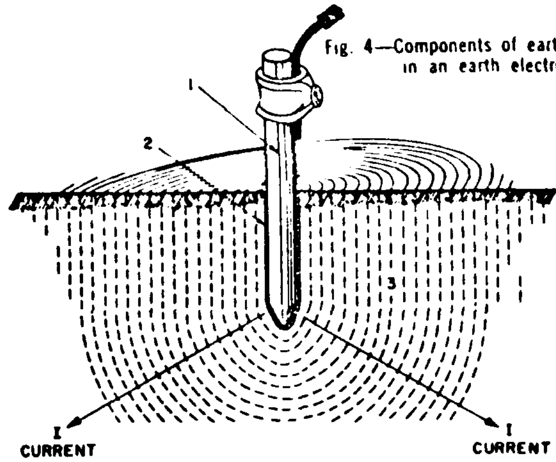


Fig. 4—Components of earth resistance in an earth electrode.

FIGURE (16)

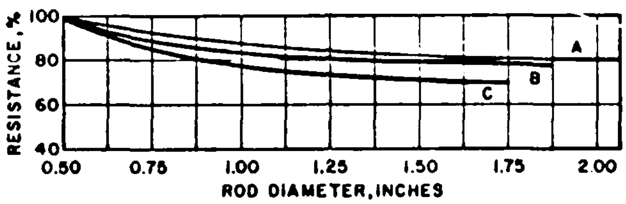


Fig. 11—Diameter of a rod has little effect on its earth resistance.

Curve A, from Reference 19.
Curve B, average of Underwriters Laboratories tests at Chicago.
Curve C, average of Underwriters Laboratories tests at Pittsburgh.

FIGURE (17)

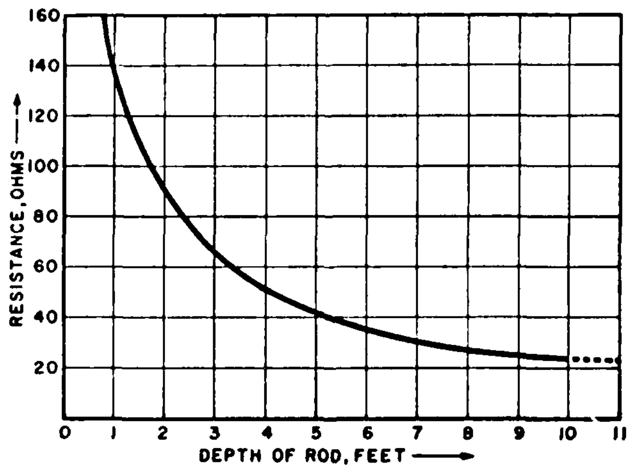
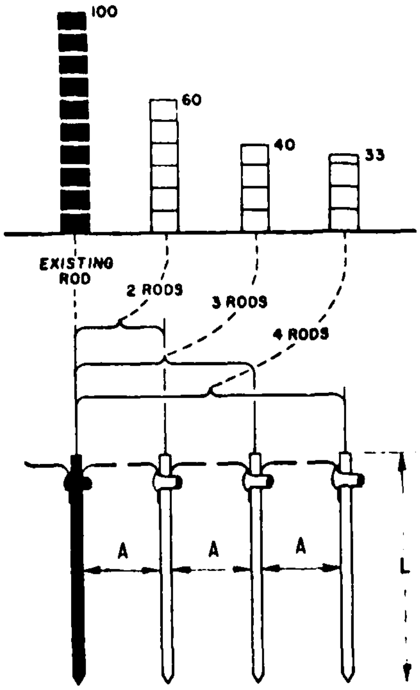


Fig. 10—Earth resistance decreases with depth of electrode in earth. (Source: Reference 19)

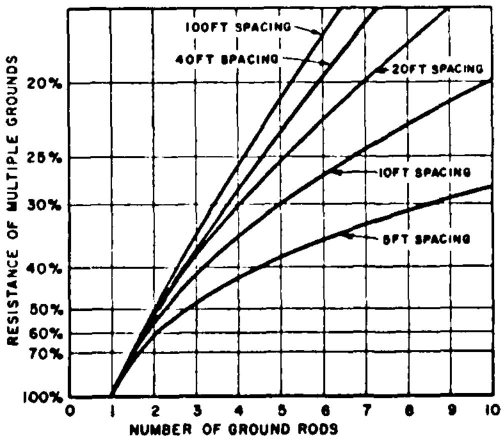
FIGURE (18)



Average results obtained from multiple-rod earth electrodes.*

"A" SHOULD BE EQUAL TO OR GREATER THAN "L" TO MINIMIZE "COUPLING" WHICH IS SHOWN BY THIS CHART & FIGURE

FIGURE (19)



Comparative resistance of multiple-rod earth electrodes. Single rod equals 100%.*

FIGURE (20)

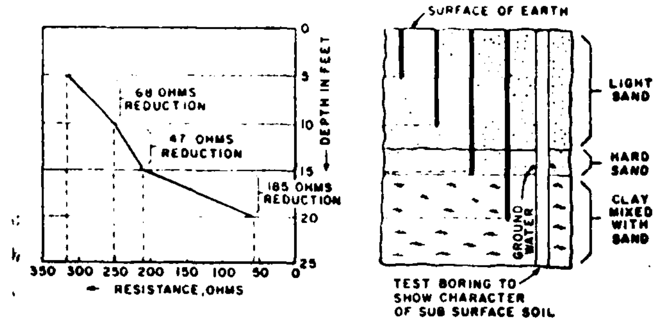
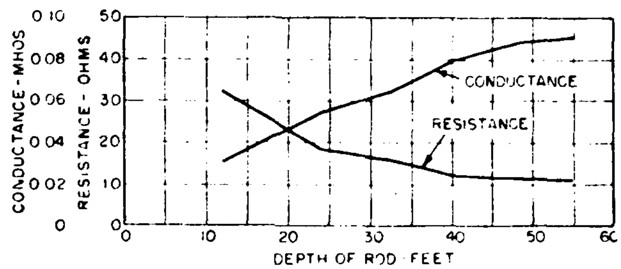


Fig. 18—Deeper earth electrodes lower the resistance. **These graphs show** the relation between character of soil and resistance of **driven electrode** at increased depths

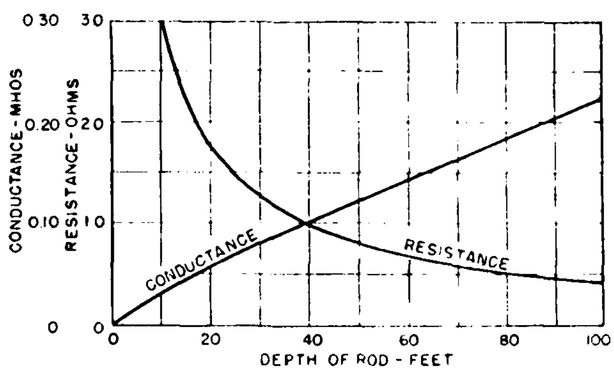
FIGURE (21)



(Photo 1100446)

Fig. 20. Variation of resistance and conductance with depth in a low resistance ground

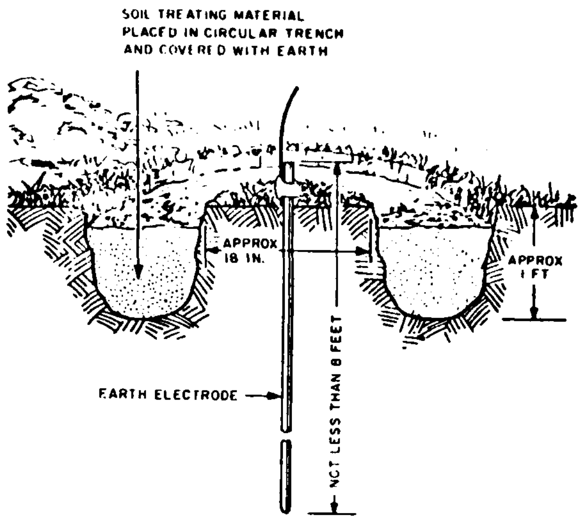
FIGURE (22)



(Photo 1100445)

Fig. 19. Calculated value of resistance and conductance of ¾-in. rod driven to a depth of 100 ft

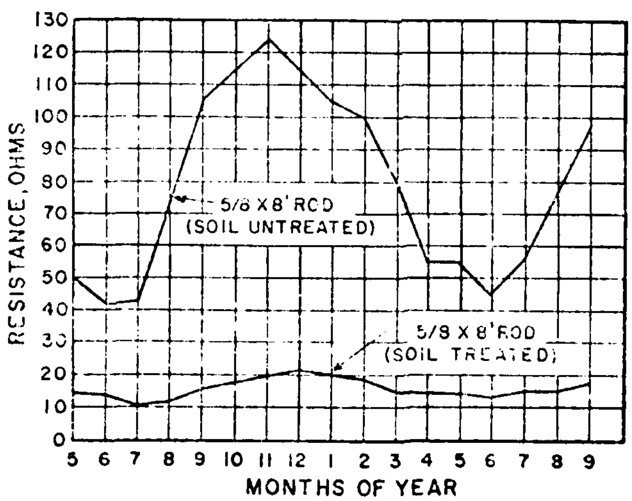
FIGURE (23)



Trench method of soil treatment.

FIGURE (24)

Chemical treatment also has the advantage of reducing the seasonal variation in resistance that results from periodical wetting and drying out of the soil. (See curves of Fig. 15). However, you should only consider this method when deep or multiple electrodes are not practical.



Chemical treatment of soil lessens seasonal variation of electrode's earth-resistance

FIGURE (25)

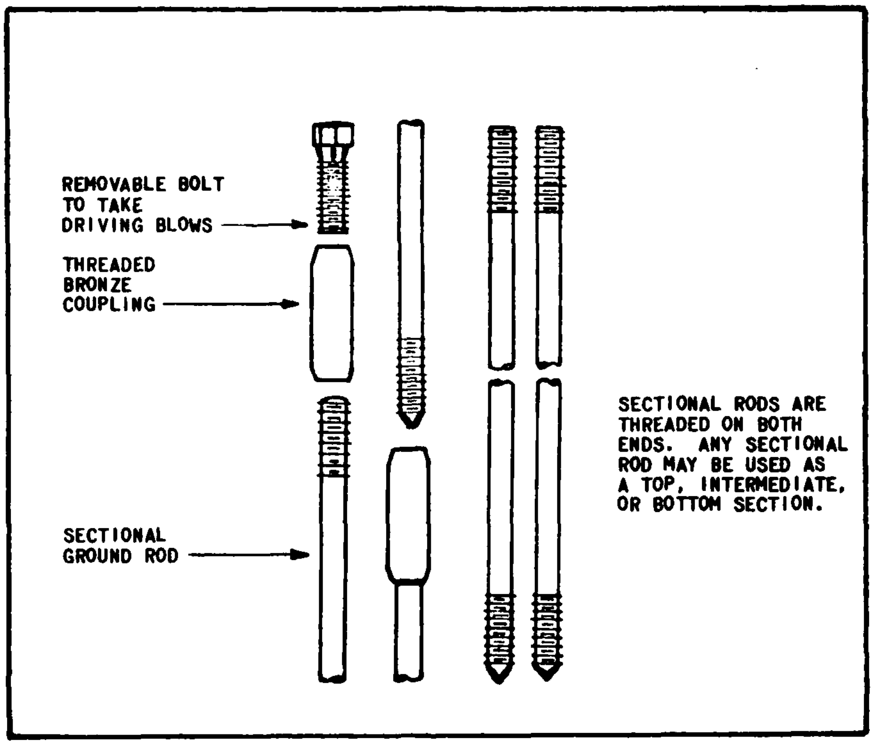

REMOVABLE BOLT TO TAKE DRIVING BLOWS
THREADED BRONZE COUPLING
SECTIONAL GROUND ROD
SECTIONAL RODS ARE THREADED ON BOTH ENDS. ANY SECTIONAL ROD MAY BE USED AS A TOP, INTERMEDIATE, OR BOTTOM SECTION.

FIGURE (26)

14. <u>Ground faults and shock hazards</u>. A ground fault (short circuit) may occur on any type of system or equipment whether grounded or not. The degree of ground fault will depend upon the circuit parameters of voltage and ground resistance. High faults, if not cleared by protective devices may cause fire, serious damage to apparatus or human life. The insulation of motors, generators, and equipment "age" and generally incur deterioration due to moisture. Heat, vibration, and chemical or electrical corrosion also lead to leakage and fault conditions. Where leakage exists, equipment insulation is poor and where the resistance of the frames and inclosures of these devices is high, a potential aboveground will exist. Accidental grounding of "hot" equipment through a person's body will occur when a lower resistance path to ground exists due to wet hands, perspiration, or damp clothing. Contact resistance of a person is usually high, but in certain ungrounded and poorly grounded situations, a shock hazard can and will exist if safe methods and practices are not recognized and maintained.

a. Figure 27 illustrates two conditions of ground fault where separate versus common ground connections result in improved safety. In part (A), figure 27, the 4 amp ground fault current flowing in the loop through the 20 ohm resistance will raise the potential 80 volts aboveground at the load equipment. In part (B), the fault current flowing through the common conductor or low resistance ground path will be much greater than that shown in part (A). In this

instance, however, the direct return path was assumed to be 0.1 ohm resistance or the approximate value of a continuous length of copper wire (e.g., 6AWG copper = 0.410 ohms/1000 feet).

b. From the foregoing conditions and illustrations, the use of a common ground wire rather than separate grounds, will result in increased safety.

c. Shock hazard by national standards have been defined and is considered to exist at an accessible part in a circuit between the part equipment and ground or other accessible parts if the potential is more than 42.4 volts peak and the current through a 1500 ohm load is more than 5 milliamperes.[23]

(1) Ground fault protection equipment has been designed and is available from various manufacturers to trip protective devices below levels of human sensitivity to current flow.[24]

(2) "Indirect contact" or touching the frame of a part that the potential has risen above 42.4 volts peak due to a ground fault or leakage, in certain instances, can be as lethal as touching a live part or making "direct contact." Since low voltage systems (below 600 V) are those to which personnel may be most exposed, the indirect contact type of ground fault will prove to be potentially the most

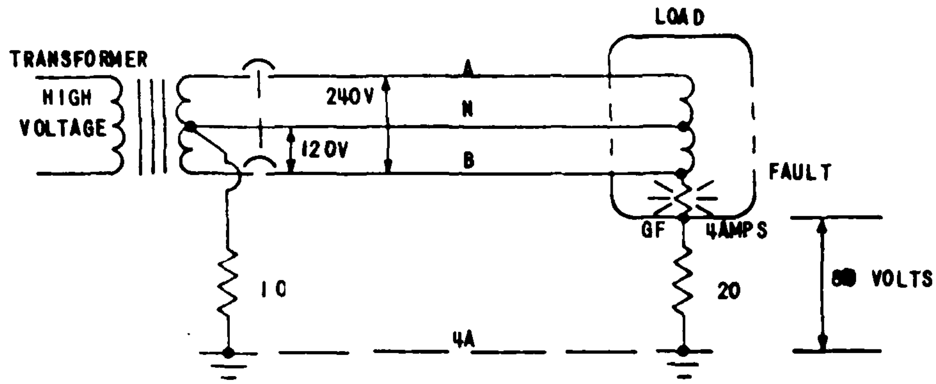
23. 1971 Department of Labor - "Construction Safety Act," subpart K which derived in part its criteria from Underwriters Laboratories, "Standards for Safety UL-492, 1968."
24. Electrical Protection, Inc., Salem, Mass. has prepared a handbook on Ground Fault Protection, 1969.

hazardous. Underwriters Laboratories have published "Standards for Safety" which include further considerations of "shock hazard" that are mandatory for the safe use of electrical equipment.

d. Included in appendix B, are further excerpts from Underwriters Laboratories, Inc. "Standard for Safety - UL-492 - 1968." Safety engineers, who review criteria and causes of equipment damage by internal failure or malfunction, maintain that certain electrical hazards exist and constitute a hazard to people when the lower limits of the Underwriters Laboratories definitions of shock hazard are exceeded. Appliances, tools, and other electrical apparatus can also fall within the minimum recommended values. The appendix B values list five different sets of conditions for rigorous safety reasons (A thru E).

e. The time function or duration of current flow and the amount of current are the two major factors which affect the human response and reaction to electric shock. Current thresholds, preception, muscular contraction, and ventricular fibrillation (abnormal heartbeat) are responses and reactions characteristic of electrical shock.

f. A further simplication in table form is shown in tables 7 & 8 to illustrate "human resistance to current flow" and the "effects of electric current on man."

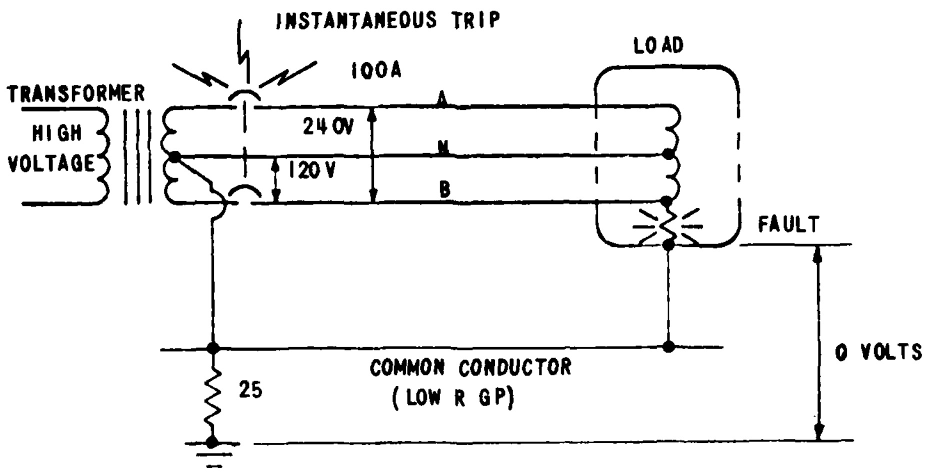


(1) GROUND FAULT $\frac{120V}{20 \quad 10} = 4$ AMPS

(2) VOLTAGE DROP $4 \times 20 = 80$ VOLTS

(A)

SHOWING SEPARATE GROUND CONNECTIONS



(1) GROUND FAULT $\frac{120}{0.1} = 1200$ A

(B)

SHOWING COMMON GROUND CONNECTIONS

FIGURE (27)

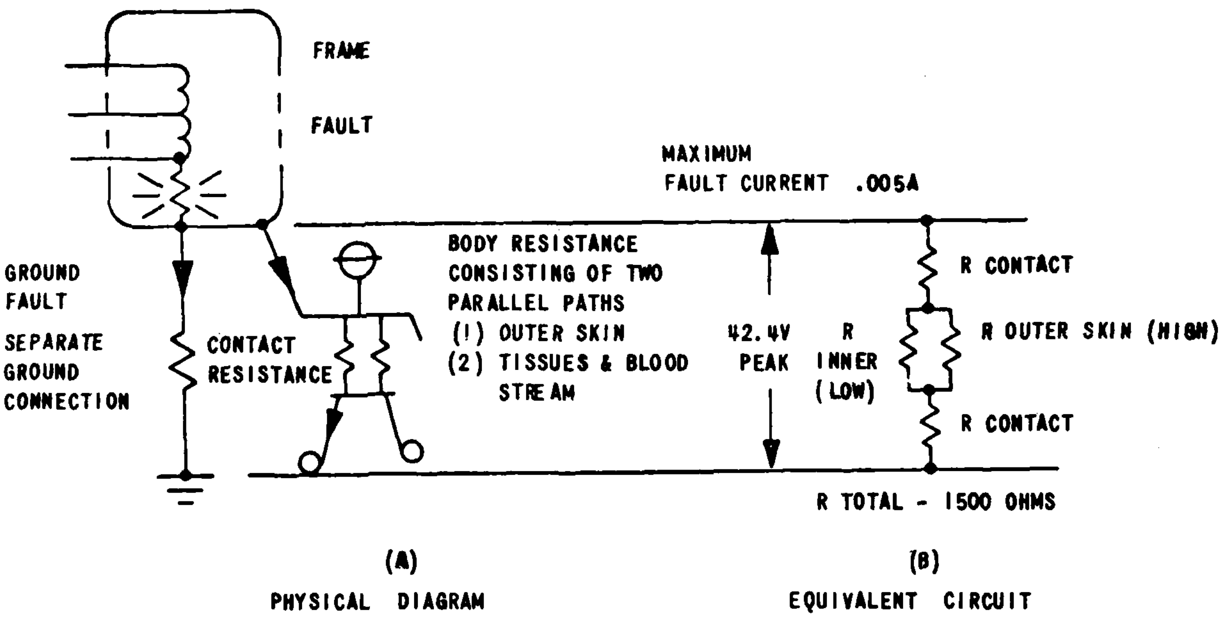


FIGURE (28)

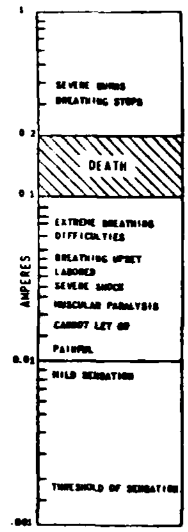
SHOWING "SHOCK HAZARD" PARAMETERS

1971 DEPARTMENT OF LABOR "CONSTRUCTION SAFETY ACT"

GROUND FAULT SHOWN MAY ALSO EXIST BETWEEN APPARATUS "PARTS"

TABLE 7 ✳
Human Resistance to Electrical Current

Body Area	Resistance (ohms)
Dry skin	100,000 to 600,000
Wet skin	1,000
Internal body—hand to foot	400 to 600
Ear to ear	(about) 100



PHYSIOLOGICAL EFFECTS OF
ELECTRIC CURRENTS

TABLE 8 · Effects of Electric Current on Man

Effect	Current in Milliamperes					
	Direct		60 Hz		10,000 Hz	
	Men	Women	Men	Women	Men	Women
Slight sensation on hand	1	0.6	0.4	0.3	7	5
Perception threshold	5.2	3.5	1.1	0.7	12	8
Shock—not painful, muscular control not lost	9	6	1.8	1.2	17	11
Shock—painful, muscular control not lost	62	41	9	6	55	37
Shock—painful, let-go threshold	76	51	16	10.5	75	50
Shock—painful and severe, muscular contractions, breathing, difficult	90	60	23	15	94	63
Shock—possible ventricular fibrillation effect from 3-second shocks	500	500	100	100		
Short shocks lasting t seconds			$165/\sqrt{t}$	$165/\sqrt{t}$		
High voltage surges	50*	50*	13.6	13.6*		

(*energy in watt seconds or joules)

✳ REPRINTED FROM THE "ACCIDENT PREVENTION MANUAL FOR INDUSTRIAL OPERATIONS" BY PERMISSION OF THE NATIONAL SAFETY COUNCIL.

15. Further discussion. The arctic and subarctic regions of Alaska became important to our national defense in the 1940's and early 1950's. Military sites have been established throughout Alaska and at various locations along DEW and Pine Tree lines. Aircraft control and warning, White Alice Communications, cold regions test and proving grounds, airfields and troop facilities--all require electrical systems for operation and maintenance.

a. Two major POL pipelines have been constructed in Alaska and a third proposed from the North Slope to Valdez. The routing of pipelines traverse typical arctic soils. Surveys have been conducted to determine the soils resistivities for corrosion control purposes. Appendix B, figure 29, shows a general location map illustrating the pipeline routes and various other locations in which data has been gathered.

b. Figure 30, curve No. 1, also in appendix B shows a histogram of resistivity values taken in 1957 along portions of the Haines to Fairbanks pipeline. This curve when compared to the data plotted for locations in the lower 48 states (curve No. 2) shows a distinct shift to the right or higher resistivity range. This shift would really become more pronounced if the seasonal variation were shown and data was taken when the ground was frozen.

c. Exploration and tests conducted in Alaska and other arctic regions reveal that deep fresh water lakes do not freeze to the bottom

and the unfrozen materials, muds, and gravels are relatively low in resistivity. Slow moving rivers also have unfrozen subterranean profiles. Grounding of electrotechnical assemblies under permafrost conditions as described in the Nozhevnikof[25] report, was conducted by placing electrodes at the bottom of deep lakes and rivers which "talik" (unfrozen ground) is always present. The permafrost soils extended to approximately 800 feet in depth and had a specific resistance from 100,000 to 1,880,000 OHM-CM. In comparison the lake bottom materials average values were 3,800 OHM-CM.

d. In southeastern Alaska near Juneau the Snettisham Project, an 80 megawatt hydroelectric station, was grounded by driving a simple array of 1" Ø x 10'-0" electrodes into the silty tide flats where low resistivity materials existed (1,200 OHM-CM). A 0.5 OHM ground was established by spacing two rows of 10 rods each not closer than 10'-0" on centers. Conversely, the intake structure was located a mile inland on a high perched lake, and presented a different picture. At the 815 feet elevation all the surrounding materials were rock in the 1,000,000 OHM-CM Range. A deep driven drill steel rod was placed into the lake bottom at the base of the gate control shaft into materials of silty organic nature. This single electrode was required for system grounding of the gate power and controls and a 25 OHM maximum was sufficient.

25. V.E. Nozhevnikof reports the grounding procedures used at the Noril'sk Mining and Metallurgy District on the Yenisey River in the vicinity of the Port of Dudinka located in mid-Siberia approximate 69° latitude north and 88° longitude east. In comparison, its location or north latitude lies along a line protecting through the Alaskan Colville River area, north of the Brooks Range.

e. On the North Slope well logs have shown permafrost to extend to depths of 1,600 feet. Resistivity tests were taken in May 1970[26] using the Wenner configuration previously described in section 5. Three locations were tested at various spacings from 10 to 200 feet. A tabulation of these values can be found in table 9, appendix B, all of which exceeded 1,000,000 OHM-CM.

f. The resistivity of sea water was taken at the Haines dock in 1967 to check for corrosion protection at that pipeline terminal facility, table 10, appendix B lists values. The range of readings are extremely low which demonstrates the good conductivity of a salty solution. Tides and fresh water layering accounted for the changes shown.

g. Electrodes were installed at Point Barrow in 1956 in conjunction with geophysical research on earth potentials.[27] The decrease in ground temperature elevated the electrode resistances with resultant poor sensitivity. Another set of electrodes was installed and sodium chloride was mixed with the fill soils which reduced the specific resistance. A comparison of the treated versus untreated electrodes is shown on figure 31 in appendix B. Note that all the electrodes vary individually; whether treated or not, as there existed in each case differences in electrode shape, surrounding soil, and amount of salts added. The magnitude of reduction for the treated electrodes was appreciable and soil treatment can be pointed to as

26. British Petroleum, Survey Report by A. Goodwin.
27. Geophysical Research Report No. 6, University of Alaska, 1957.

the most practical and least expensive method of reducing resistance in the arctic. Seasonal variation as shown on figure 32, appendix B.

16. <u>Grounding - winter tactical operations</u>. Throughout this report the requirements for system and equipment grounds have been outlined. It should be emphasized that the same standards for safety exist during all seasons.

a. Power and communications facilities in arctic and subarctic regions might vary between the extremes of being characteristically highly mobile and isolated or on the other hand a strategic command or tactically fixed station.

b. During the winter, the resistance of all existing grounds would have increased possibly from a few thousand to the Meg-Ohm range due to changes in soil resistivity and the conditions for establishing new grounds are thereby changed. If criteria for grounding a generating station or communications facility is specified but not obtainable due to permanently frozen ground or icefields, isolation and other dielectric protective measures must be incorporated. The "green wire" (equipment ground) and the "white wire" (system ground) should be provided and maintained in all systems. If all the surrounding terrain is frozen and safety to personnel from electrical failure is the object, then the lowest possible ground remains a matter of practicality and economics. Without equipment for drilling holes into the ground or ripping ditches with special plows, a method must be sought to establish "area-contact" with the surface layer materials of the frozen earth.

The counterpose method (horizontal wire) or the star (multiconnected rods) are two possible electrode configurations. Chemical treatment of the adjacent ground surface using high conductivity salt solutions will further enlarge the conducting volume and increase the surface area. The effective or resulting configuration would theoretically appear as long half sphere or an irregular flat plate.

c. The curves shown on table 6, in section 7, will indicate with a fair degree of accuracy the size of rods or wire to secure various grounds and may be referred to as a guide. Judgment and expediency will be the prime factors in tactical situations. Installations will have to be field tested before any degree of understanding and trust is placed on a highly critical grounding system. In general, where temporary field stations or camps are to be established during winter operations and the earth is frozen and covered with snow, normal grounding practices are difficult. Consequently, for tactical operations systems grounding, "green wire" bonding is the only expedient and workable solution.

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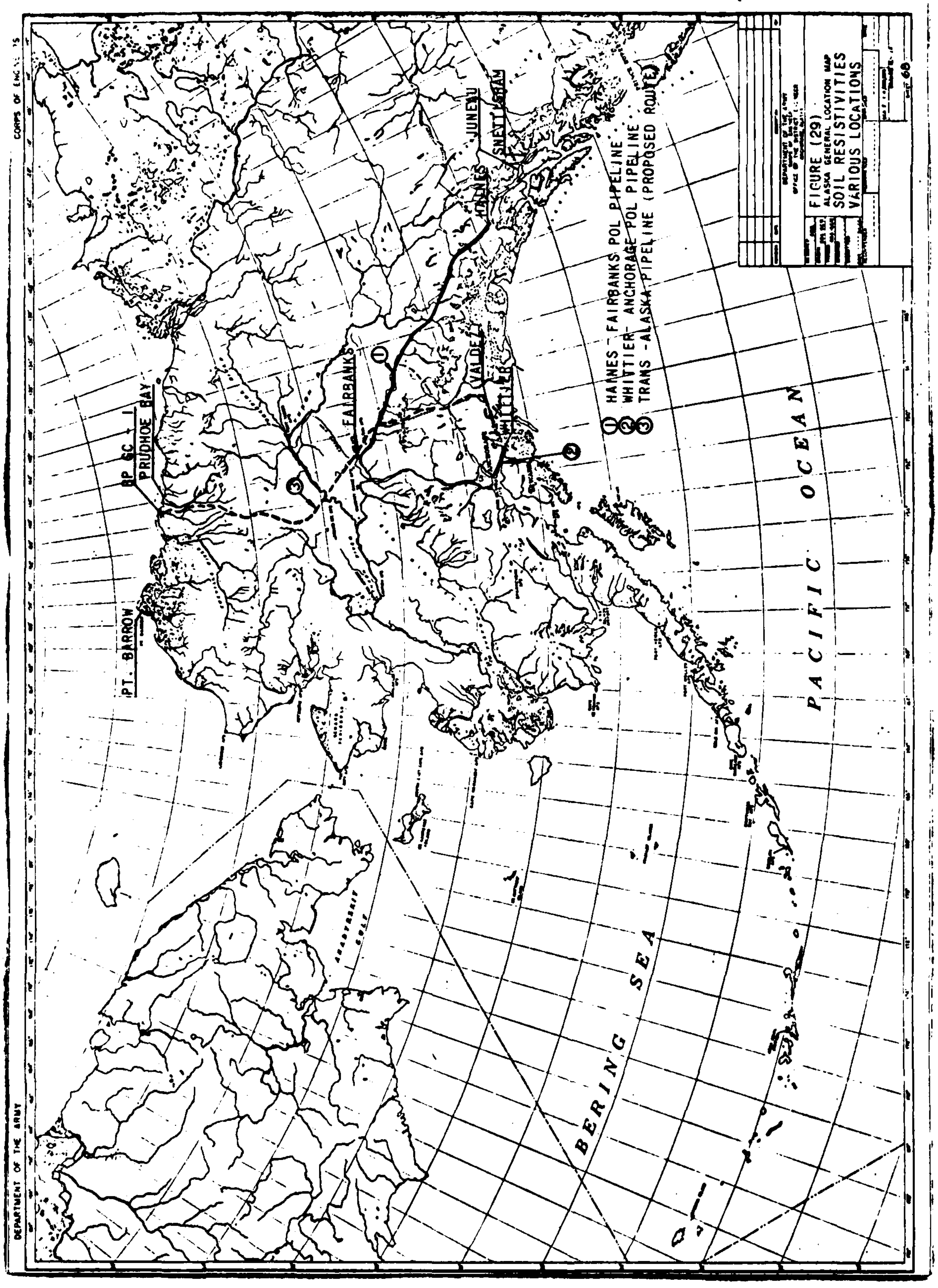
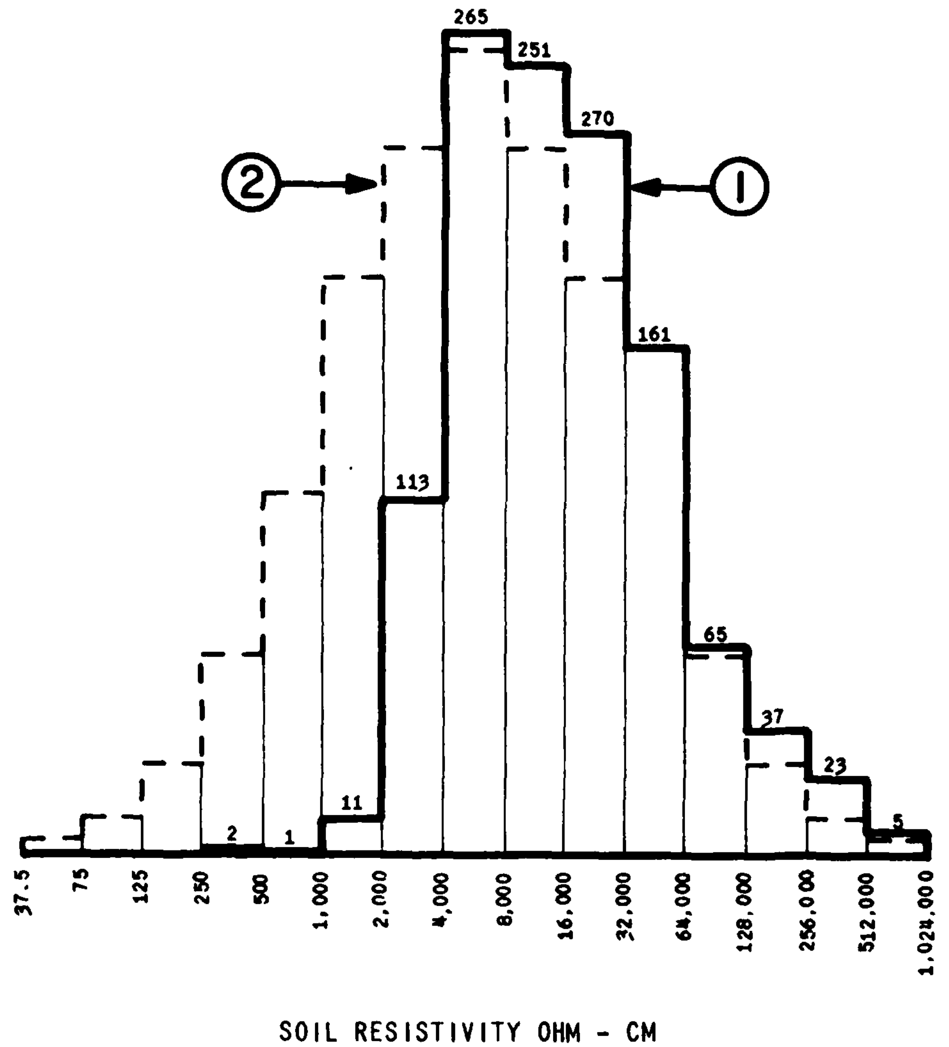


DEPARTMENT OF THE ARMY
PT. BARROW
PRUDHOE BAY
BP GC 1
FAIRBANKS
VALDEZ
WHITTIER
HAINES
JUNEAU
SNETTISHAM
1 HAINES - FAIRBANKS POL PIPELINE
2 WHITTIER - ANCHORAGE POL PIPELINE
3 TRANS - ALASKA PIPELINE (PROPOSED ROUTE)
PACIFIC OCEAN
BERING SEA
FIGURE (29)
ALASKA GENERAL LOCATION MAP
SOIL RESISTIVITIES
VARIOUS LOCATIONS



(1) RESISTIVITY VALUES OF 1,154 READINGS DURING FIELD SURVEY.

(2) APPROXIMATION TO THE DISTRIBUTION OF SOME 15,000 SOIL RESISTIVITY READINGS, TAKEN ALONG PIPE LINES IN MID-CONTINENT AND SOUTHWESTERN UNITED STATES.

FIGURE (30)

HISTOGRAM OF RESISTIVITY VALUES
HAINES TO FAIRBANKS PIPELINE-1967

TABLE 9

SOIL RESISTIVITY, NORTH SLOPE, (*)

LOCATION	ELECTRODE SPACING (FEET)	R (OHMS)	RESISTIVITY (OHM-CM)
GATHERING	200	70	2,700,000
CENTER - 1	50	165	1,600,000
	10	640	1,200,000
PROPOSED	50	215	2,100,000
CENTRAL	25	470	2,200,000
PWR PLANT	10	580	1,100,000
PROPOSE	25	580	2,800,000
BASE CAMP	10	1450	2,800,000

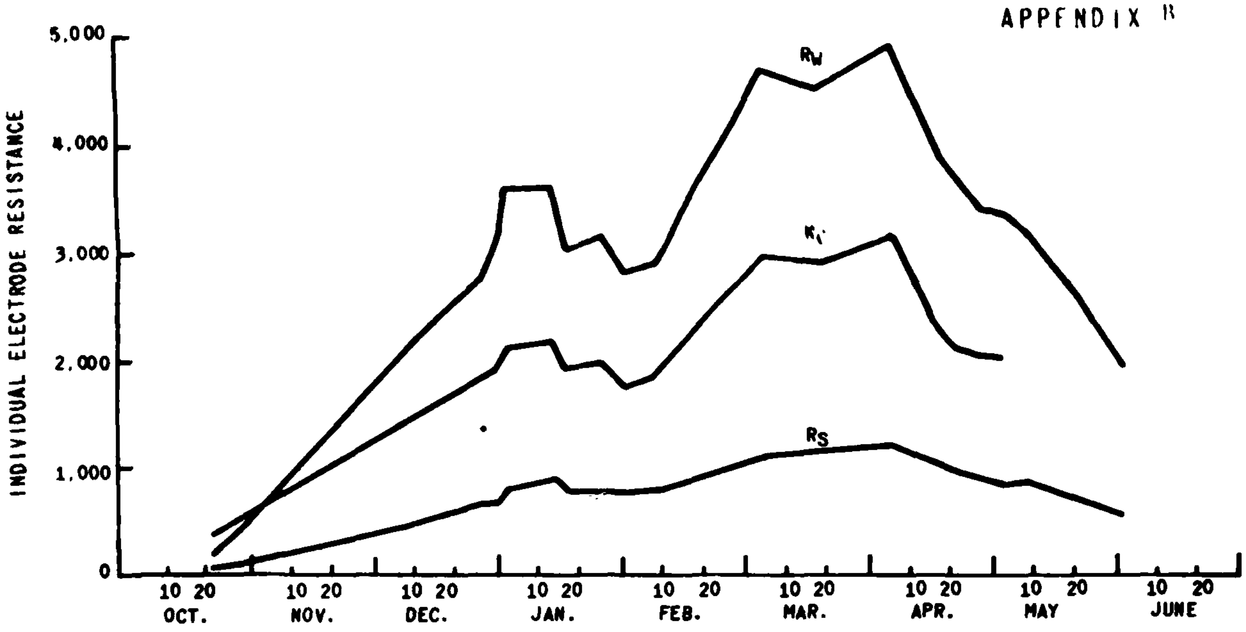
(*) BRITISH PETROLEUM REPORT, PART 3. A.GOODWIN,1970.

TABLE 10

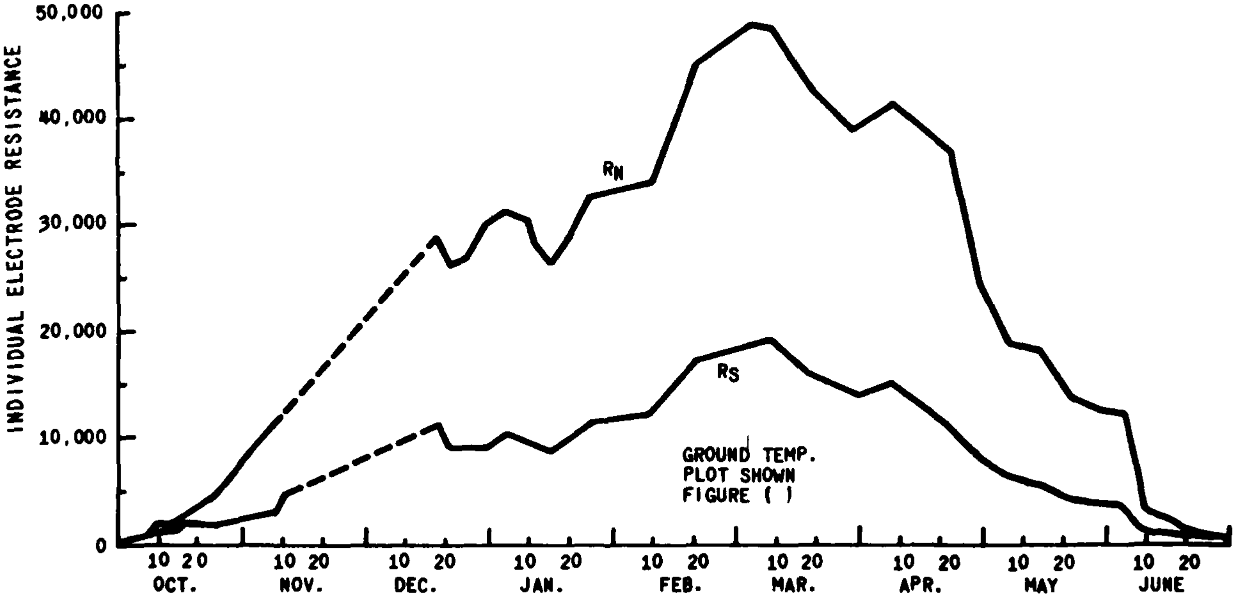
WATER RESISTIVITY, HAINES DRY CARGO DOCK (*)

TIME	DEPTH	RESISTIVITY, OHM-CM
1000	2'	140
	5'	101
	8'	80
	11'	76
	14'	76
1600	2'	68
	5'	68
	8'	68
	11'	70
	14'	72

(*) HAINES-FAIRBANKS POL PIPELINE CORROSION SURVEY,1957.



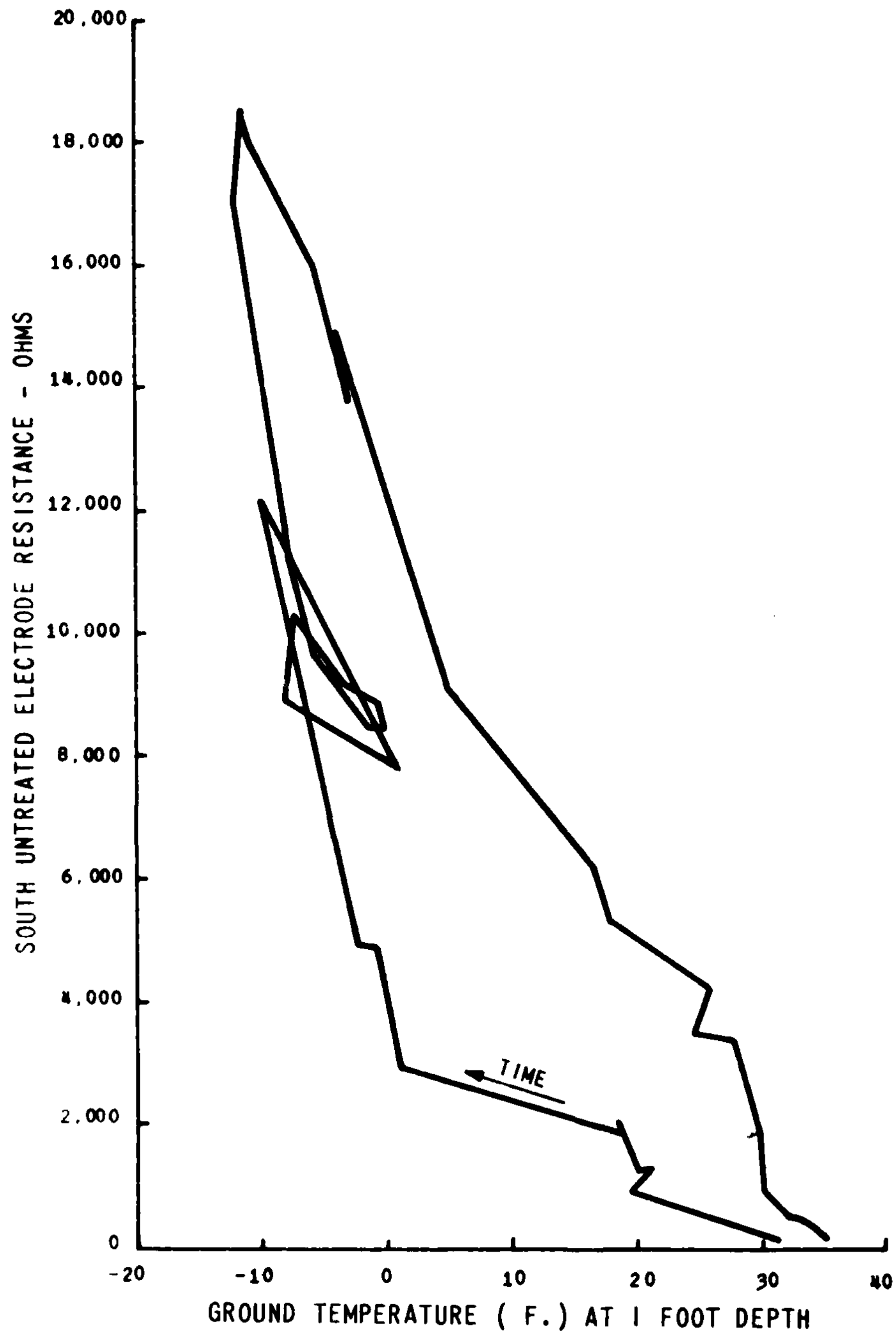
RESISTANCE OF TREATED ELECTRODES, OCT. 1956 - MAY 1957.



RESISTANCE OF UNTREATED ELECTRODES, OCT. 1956 - MAY 1957.

FIGURE (31)

EARTH POTENTIAL ELECTRODES IN PERMAFROST & TUNDRA
POINT BARROW, ALASKA



RESISTANCE-TEMPERATURE RELATION
FOR UNTREATED SOUTH ELECTRODE

FIGURE (32)
EARTH POTENTIAL ELECTRODES IN PERMAFROST & TUNDRA
POINT BARROW, ALASKA

TABLE 11 - The following defined shock hazards have been reprinted from the Underwriters Laboratories, Inc., "Standards for Safety."

10 RADIO AND TELEVISION RECEIVING APPLIANCES — UL 492 SEPTEMBER [illegible]

36 RADIO SHOCK HAZARD — Except as noted in paragraph 37, in a radio receiver and similar appliance, shock hazard shall be considered to exist at an accessible part in a circuit involving a potential of 125 volts or less, measured between the part and ground, or other accessible parts if the potential is more than 42.4 volts peak and the current through a 1500-ohm load is more than 5 milliamperes.

37 RADIO AND TELEVISION SHOCK HAZARD — Shock hazard shall be considered to exist at any part involving a potential of between 42.4 volts peak and 40 kilovolts peak in the following cases:

A. If the current through a load of not less than 500 ohms exceeds 300 milliamperes after 0.0003 second.

B. If the current through a load of not less than 500 ohms exceeds 5 milliamperes after 0.2 second.

C. If the time required for the current through a load of not less than 500 ohms to decrease to 5 milliamperes is between 0.1 and 0.2 second, and the total quantity of electricity passed through the load up to that time exceeds 4 millicoulombs.

D. If the time required for the current through a load of not less than 500 ohms to decrease to 5 milliamperes is between 0.03 and 0.1 second, and the total quantity of electricity passed through the load up to that time exceeds $75T - 350T^2$ millicoulombs, where T is the time in seconds.

E. If the potential is more than 5 kilovolts peak and if the total capacitance of the circuit is more than 3000 micromicrofarads.

38 ANTENNA TERMINAL SHOCK HAZARD — Except as noted in paragraph 39, each terminal provided for the connection of an external antenna shall be conductively connected to the supply circuit. The conductive connection shall have a resistance of 4 megohms maximum and a wattage rating of 1/2 watt minimum, and shall be effective with the power switch in the "On" or "Off" position

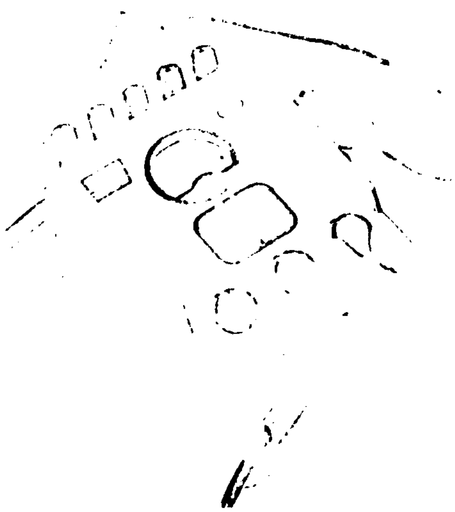
39 The conductive connection required in paragraph 38 need not be provided if such a connection is established in the event of electrical breakdown of the antenna isolating means and if the breakdown does not result in a shock hazard.

APPENDIX C

BULLETIN 25

MEGGER® EARTH TESTERS

. . . for measuring resistance of earth to ground connections and for determining earth resistivity



A Megger Earth Tester measures the resistance to earth of ground connections simply, easily and accurately, thereby helping to determine whether such connections will perform the services for which they were intended. Earth resistivity determinations may also be made with greater ease with these instruments.

GROUND RESISTANCE

Grounding surveys have shown conclusively that for protection to life and property and for the correct functioning of nearly all types of electrical equipment—especially lightning arresters, distribution transformers, and equipment in sub-stations—much depends on suitable and permanent ground connections. This includes the electrical connections from machine frames, transformer cases, cable sheaths, metal housings, etc., to the earth connections, as well as the earth connections themselves.

EARTH RESISTIVITY

Megger Earth Testers provide, in addition to ground resistance measurements, a highly convenient means for measuring resistance values required for earth resistivity determinations.

Geophysical Prospecting

Earth resistivity measurements constitute one of the electrical methods for geophysical prospecting for ore bodies, clays and water bearing gravels and for other determinations such as depth to bed rock and thickness of glacial drift.

Electrical Power and Communications Problems

Measurements of earth resistivity can be used for determining quickly and easily the best locations and depths for high capacity and low resistance connections. Such studies can be helpful in determining the best location for installation of generating station, sub-station, transmission tower and telephone central office grounds.

Soil Corrosion—Electrolysis—Cathodic Protection

The Megger Earth Tester offers a convenient and relatively inexpensive means for studying the electrical characteristics of soil in relation to corrosion of water, oil, gas and gasoline pipelines, and for determining the locations where corrosion is most likely to occur.

JAMES G. BIDDLE CO.
Electrical Testing & Speed Measuring Instruments
Plymouth Meeting, Pennsylvania 19462

MEGGER®
NULL BALANCE
EARTH TESTER

A new highly sensitive method of measuring earth resistance

Designed to meet hard field service with fine laboratory performance

FEATURES

Range: 0.01 ohm to 9990 ohms in four overlapping ranges.

Accuracy: ±1% of range in use even on the lowest range with probe resistances up to 1500 ohms.

Guard Terminal: Used to assure accuracy when extremely high probe resistances are encountered. Variable a-c output eliminates effects of stray currents and soil electrolysis.

Digital read-out "at a glance"—remains in view until re-switched.

Strong metal case particularly suited for field use—fitted with sling type carrying strap—weight of this self-contained instrument only 9 pounds.

The accuracy of this instrument is not affected by electrode resistance.

To obtain high accuracy, proper internal guarding is necessary to prevent leakage currents from being introduced into the system. The guard wiring is connected to the Guard Terminal for use when the probe resistances are high or unbalanced.

The test current, obtained from a hand cranked a-c generator, is passed to the ground under test and returned through the soil to the C_2 terminal. The test current also passes through the primary of a current transformer. The secondary of the current transformer generates a potential which is applied in opposition to the potential generated by the test current developed between the potential terminals P_1 and P_2. By means of an adjustable measuring resistance the potential generated in the secondary of the current transformer

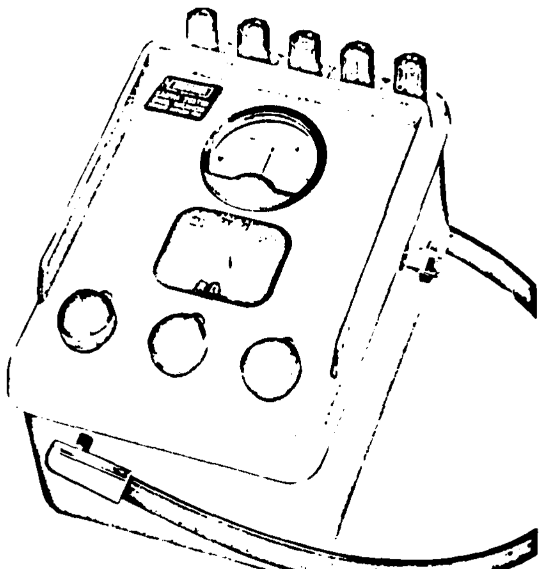


FIGURE 5—Megger Earth Tester 63220

is balanced against the test potential between terminals P_1 and P_2. The adjustable potentiometer is calibrated directly in terms of earth resistance, ohms. When the zero center galvanometer is at balance the earth rod resistance, etc., is read instantly by the digital read-out.

The instrument will measure resistance from 0.01 to 9990 ohms in four ranges. The readings are given by means of three separate digital indicators. An extremely high degree of accuracy is obtained even on the lower range, with individual spike resistances up to 1500 ohms. On higher ranges, much greater spike resistances than this can be tolerated without affecting performance. Applications include:

- Earth electrode resistance measurement
- Soil Resistivity measurement
- Earth Continuity testing
- Neutral Earth Test
- Direct resistance measurement within the instrument range

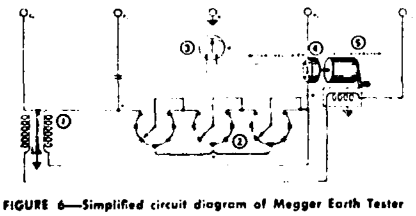


FIGURE 6—Simplified circuit diagram of Megger Earth Tester

1. Transformer
2. Digital Switches
3. Galvanometer
4. Mechanical Rectifier
5. A-C Generator

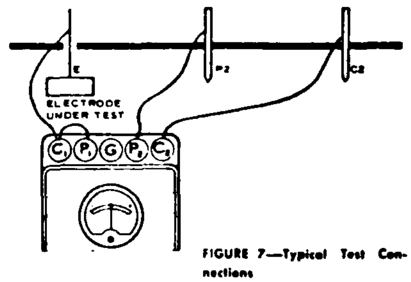


FIGURE 7—Typical Test Connections

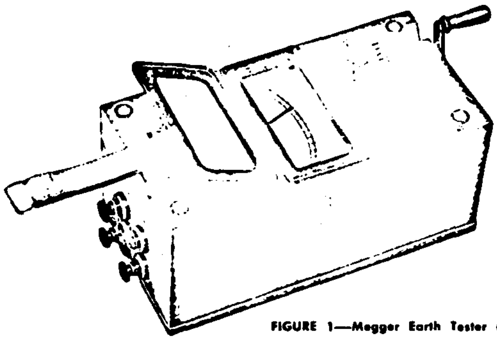


FIGURE 1—Megger Earth Tester 601

MEGGER® UNIVERSAL MULTI-RANGE EARTH TESTER

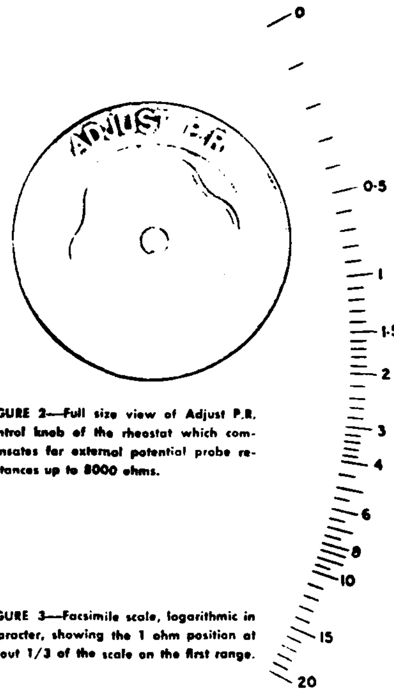


FIGURE 2—Full size view of Adjust P.R. control knob of the rheostat which compensates for external potential probe resistances up to 8000 ohms.

FIGURE 3—Facsimile scale, logarithmic in character, showing the 1 ohm position at about 1/3 of the scale on the first range.

The outstanding performance records and proven dependability, associated with Megger instruments for over 50 years, are pronounced features of the new design now available in the Megger Universal Earth Tester.

The new model, replacing four old models, has ranges of 0 to 20, 0 to 200, 0 to 2000 and 0 to 20,000 ohms.

The new features include:

LONGER, MORE OPEN SCALE

The 30% longer scale (approximately 5") is logarithmic in character, permitting closer readings within each scale division. One ohm extends over 1/3 of scale on first range.

COMPENSATED FOR EXTERNAL POTENTIAL PROBE RESISTANCES UP TO 8000 OHMS CONVENIENT, SIMPLE ADJUSTMENT

The control knob for compensating potential probe resistances up to 8000 ohms is placed conveniently on the side of the instrument facing operator.

EASY OPERATION

The generator has a long, easy-to-turn crank handle. These instruments are housed in sturdy teakwood cases designed to withstand hard use and protect the instrument from damage due to rough handling and weather.

A comfortable leather grip makes these 22-pound instruments easily portable and ideal for hard, extensive field use. The overall dimensions are 14" x 7" x 7".

For Specifications see Page 4.

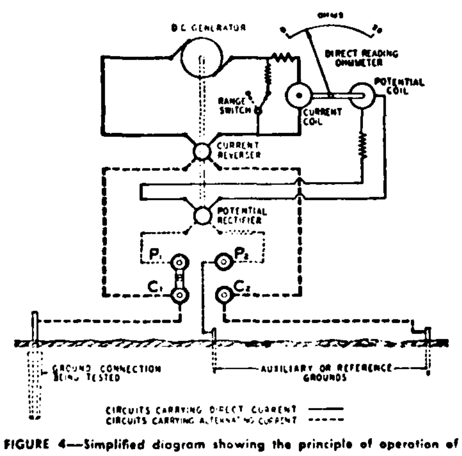
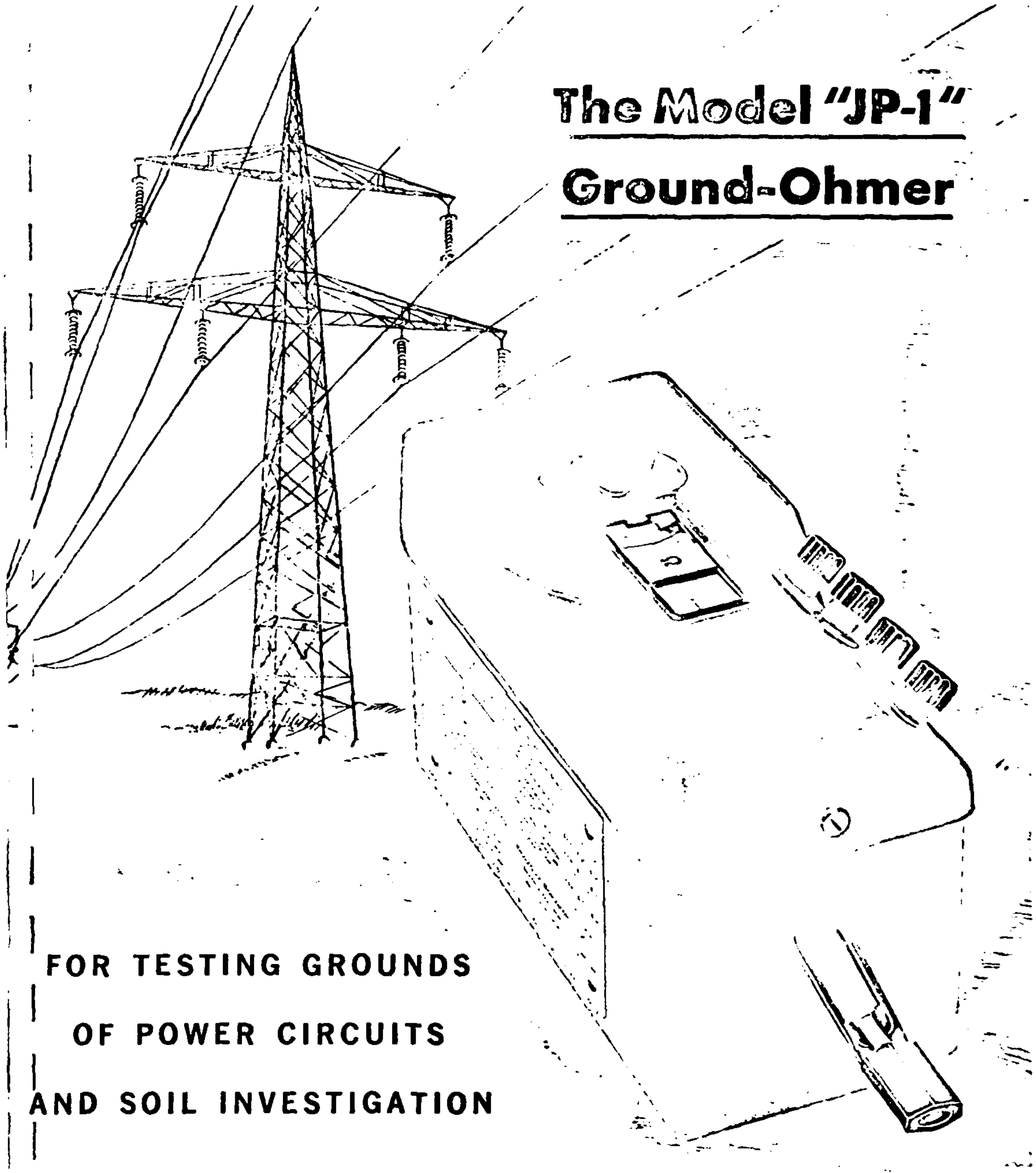


FIGURE 4—Simplified diagram showing the principle of operation of Megger Earth Tester, Catalog 601.

The Model "JP-1" Ground-Ohmer



FOR TESTING GROUNDS
OF POWER CIRCUITS
AND SOIL INVESTIGATION

MEASURING PRINCIPLE

The Model JP-1 Ground-Ohmer *operates on the voltage compensation principle. The voltage drop* **caused by a specific** current in the earth resistance is compared with the voltage drop across an adjustable balancing resistor. Alternating current is used for the measurement, in order to avoid the polarisation errors which occur by direct current.

Fig. 1 shows the basic circuit diagram of the measuring instrument. The alternating current generated by the generator (1) passes through the primary of a current transformer (2) to the current electrode E_1, then across the earth to the second *current electrode* E_2 *and back to the generator.* A voltage drop U_1 is produced between the voltage probes S_1 and S_2. This voltage is opposed to the voltage drop U_2 caused in the balancing resistor (3) by the secondary current of the current transformer. *If both voltages are of equal value, no current will flow through the galvanometer (4), whose pointer will therefore* indicate zero. The earth resistance then equals the balancing resistance adjusted and can be read off directly.

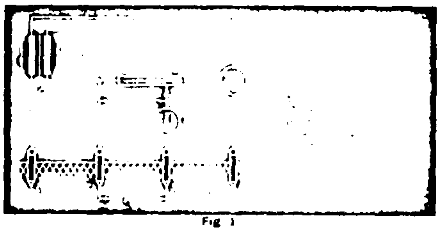


Fig. 1

APPLICATIONS

The Model JP-1 Ground-Ohmer is specially designed for measurements of earth resistances of electrical installations, such as power plants, high-tension transmission towers, *lightning arrestors, etc. Fig. 2 shows the connec*tion diagram for testing grounds of power circuits.

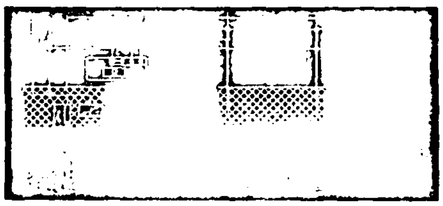
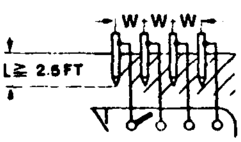


Fig. 2

This instrument is also used for determination of specific soil resistances (soil investigation) in which case four ground rods are connected to the four binding posts of the instrument. (see fig. 3)



Soil Test

W Equal distances

Fig. 3

MODEL JP-1 GROUND-OHMERS

Offer the Following Advantages:

Earth resistance found by a single measurement.

Direct reading of ohmic value
excluding errors in measurement

Four measuring ranges, 0.1/10/100/1000 ohms, selected by means of selector switch, resulting in a particularly wide overall range from .01 to 1000 ohms.

Reliability of measurement not influenced by resistances of test spike or auxiliary earth.

The bridge being correctly adjusted, no current passes through the spike. A high resistance of the auxiliary earth will affect the sensitivity, but not the accuracy of the measurement.

Practically no *interference from direct or alternating stray* currents, since the rectifier works in synchronism with the magneto generator frequency.

Simple manipulation. After having made the connections required, the magneto handle is turned and the graduated dial of the variable resistor is adjusted until the galvanometer points to zero. *Taking into account the multiplying* factor to which the range selector is set, the result is then read off directly at the index mark.

Sturdy design: The Earth Tester is a robust service instrument contained in a metal case with plastic top and provided with a carrying strap. An instruction plate is fixed to the side of the instrument.

Convenient size:
Base: 9.8" x 3.5", height: 6.3"

Few accessories required:

For Measuring Grounds of Power Circuits: 2 ground rods, 1 connecting clamp, 1 cable 11 yds. in length, 2 cables 33 yds. *in length.*

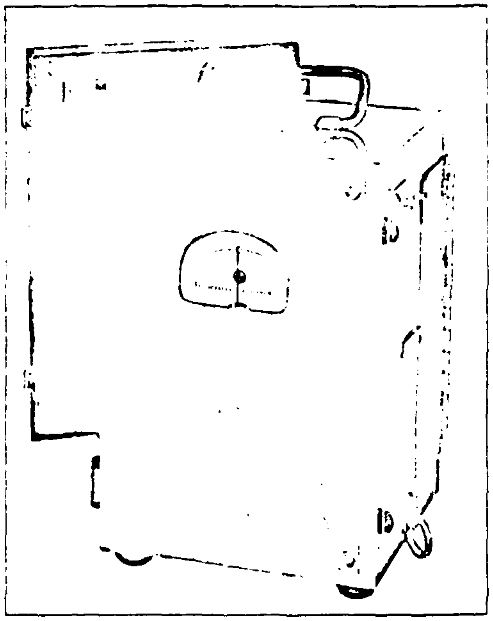
For Soil Investigation: 4 ground rods, 2 cables 33 yds. in length, 2 cables 66 yds. in length.

SPECIFICATIONS

Description	Particulars	Catalog No.	Approx. Weights
Model JP-1 Ground Ohmer	Measuring ranges 0.1/10/100/1000 ohms	232104	8.5 lbs
Ground Rods	to serve as auxiliary earth	232130	6.4 lbs
Connecting Clamp		232131	0.2 lbs
Cables for main and auxiliary earths	11 yds. cable 33 yds. cable 66 yds. cable	232132 232133 232134	1.8 lbs 5.3 " 10.5 "

HERMAN H. [illegible] COMPANY, INC.
27 PARK PL[illegible] NEW YORK, N.Y. [illegible]

Bull.
No. 16[illegible]



Model 293

NOTE

The Model 263 VIBROGROUND is used as an example throughout this manual. The Model 293 is identical to the 263 in physical appearance and operation, and has all the ranges of the 263 with one additional higher range. The ranges of Model 263 are 0-1/10-100/1000 ohms and of the 293, 0-1/10/100/1000/10,000 ohms.

The Model 293 "Multiply By" range switch, unlike the Model 263, is calibrated *in powers of* 10 (multiply by 1, 10, 10^2, 10^3, 10^4). The Model 293 resistivity range is more than 20 million ohms per cubic centimeter at 10 feet or greater probe spacing.

In this manual, all references to the Model 263 apply equally well for the Model 293, except for the differences outlined above.

1-3.2 Three Electrode Method, for the measurement of resistance to earth of man-made grounds, anode resistances, polarization *effects*.

1-3.3. Two Electrode Method, for the measurement of circuit resistance.

1-4. The Model 263 VIBROGROUND is manufactured by Associated Research, Incorporated, 3758 West Belmont Avenue, Chicago 18, Illinois.

SECTION II

OPERATION

2-1. PRINCIPLES OF OPERATION.

2-1.1. The Vibroground works on a null-balance principle of operation. The voltage drop developed by a current flowing through the unknown ground resistance is measured by comparing it to a portion of the voltage drop developed by that same current flowing through a calibrated potentiometer.

2-1.2. The instrument consists of a power supply, a current supply circuit and a measuring circuit. The power supply changes the low DC battery voltage (B) by means of a 97 CPS synchronous vibrator (V) to an alternating current, which is fed to the primary transformer T_1. This voltage is stepped up to 125 volts AC in the secondary of T_1. In the current supply circuit, the secondary of the transformer T_1 is connected in series with a calibrated potentiometer and terminals C_1 and C_2 which connect to the two current electrodes (driven into the earth). The resistance of the earth between these two current electrodes completes the circuit.

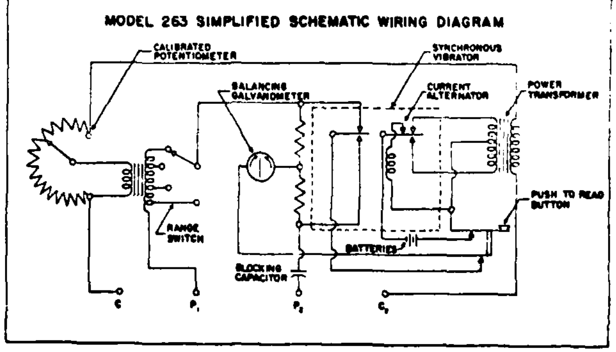


Figure 2-1 -- Simplified schematic wiring diagram of Model 263 VIBROGROUND

2-1.3. The measuring circuit consists of a secondary of the ratio transformer T_2 and its associated range selector switch S_2, two metering resistors R_1 and R_2, the galvanometer M and a blocking capacitor C (to prevent stray DC entering the measuring circuit), and two terminals P_1 and P_2 which connect to the two potential electrodes (driven into the earth between the two current electrodes). The resistance of the earth between these two potential electrodes completes the circuit.

The current flowing between the two current electrodes causes a voltage drop across the ground resistance between the two potential electrodes. This voltage drop causes a current flow in the measuring circuit. The current flowing through the calibrated potentiometer causes a voltage drop which is fed to the primary of the ratio transformer. This induces a voltage drop in the secondary of the ratio transformer, also causing a current flow in the measuring circuit. This current tends to cancel the current due to the voltage drop across the ground resistance. When the calibrated potentiometer and selector switch are adjusted so that the two currents exactly cancel, the galvanometer will indicate balance by resting in the zero position. The resistance reading on the calibrated dial of the potentiometer, multiplied by the range switch setting, then gives the value of the earth resistance between the two potential electrodes connected to P_1 and P_2.

2-1.4. Since there is no current flowing in the measuring circuit at balance, the resistance of the potential leads has no effect on the reading. Since the same current that flows through the ground causes the voltage drop on the potentiometer P_1, the resistance of the current leads connected to C_1 and C_2 are also relatively unimportant. Since the meter current is rectified by the synchronous vibrator at 97 CPS, only current at that particular frequency can cause a meter indication. The unit is therefore independent of any stray 60 cycle power line or ground currents. Because of the blocking capacitor C in the potential circuit, stray DC ground voltages have no effect on the readings either.

The detection of zero potential condition is accomplished in Vibrogrounds by the use of a D'Arsonval galvanometer. This galvanometer has been selected for its ruggedness, accuracy and extreme sensitivity. Electrically the instruments are designed to withstand a substantial overload in their circuits for a short time. They are protected by a stopped sensitivity shunt incorporated in the "Push to Read" button circuit to facilitate coarse adjustment to approximate zero balance. The galvanometer is automatically electrically locked for extra protection of its pivots during transportation.

2-1.5. Ranges are selected by a separate switch at the lower left of the panel (Figure 2-2, 3). Special design features permit reading, on the single scale of the potentiometer (Figure 2-2, 1). All resistance values are determined by simple decimal multiplication. The ranges provided make possible the reading of earth resistivity measurements from 0 to 1,915,000 ohms per cubic centimeter at 10 ft. or greater spacings. The resistance

of man-made grounds under average conditions fall within the ranges of the instrument. Resistance measurements of single or multiple anodes installed in the earth, also fall within the ranges of the instrument.

2-1.6. Condensed field operating instructions are contained in the instrument cover.

2-2. SET-UP FOR OPERATION.

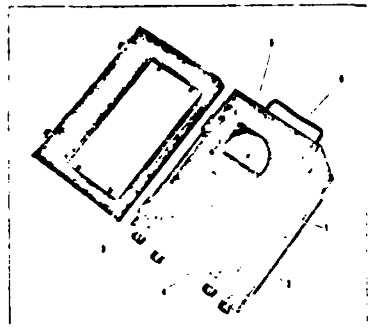


Figure 2-2 -- Panel view of Model 263 VIBROGROUND

1. Potentiometer knob.
2. Potentiometer scale for reading resistance.
3. Range selecting knob.
4. Push to read button.
5. Balancing meter.
6. Carrying handle.

2-2.1. With the instrument lying in front of you so that the cover locks are at its right side, unlatch and open lid. To remove lid, push away from you which will release the slip hinges. The lid can then be removed from the instrument during testing.

2-2.2. For field test work the case is provided with two eye rings so that the instrument may be conveniently carried by employing a shoulder strap with snap fasteners. (Figure 3-2, 10.)

2-2.3. Depending upon the measurement to be made, the instrument will be connected in accordance with the following paragraphs.

2-2.4. To close up the instrument, repeat in reverse the process referred to above.

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